PUBLICATIONS OF THE OBSERVATORY

UNIVERSITY OF MICHIGAN

VOLUME I

DETROIT OBSERVATORY
1855

DETROIT OBSERVATORY

PUBLICATIONS

OF THE

ASTRONOMICAL OBSERVATORY

OF THE

UNIVERSITY OF MICHIGAN

VOLUME I

ANN ARBOR:
PUBLISHED BY THE UNIVERSITY
1912

ORGANIZATION OF THE DETROIT OBSERVATORY

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A GENERAL ACCOUNT OF THE OBSERVATORY.

By WILLIAM J. HUSSEY.

HISTORICAL.

The legislative Acts providing for the organization of the University of Michigan were approved on March 18, and June 21, 1837. These Acts contemplated the appointment of a Chancellor of the University, but during the early years of the Institution this office was not filled, the ordinary duties of President being performed in turn by members of the faculty. It was not until the new State Constitution of 1851 was adopted, with its provisions for the reorganization of the University and the betterment of its conditions, that it became mandatory on the part of the Board of Regents to elect a President. They were fortunate in securing Dr. Henry P. Tappan to fill this important post. He was a man of great energy and ability, who looked beyond the narrow horizon of the time, and by well-directed effort, in a few short years, established conditions which have had a great influence on the subsequent history of the University and upon higher education in the West. So important was his work that it may be said that he was the real founder of the University.

Dr. Tappan came to Ann Arbor in October, 1852, and delivered his inaugural address in the following December. On this occasion he presented his policy of making the institution at Ann Arbor a University worthy of the name, and he appealed to the people to take an interest in it and give it their loyal support. At the conclusion of the address, Mr. Henry N. Walker, then a prominent citizen of Detroit, came to him and inquired in what way he could be of service to the University. Dr. Tappan was already planning an expansion of the curriculum by the introduction of engineering and scientific studies, and he at once suggested that Mr. Walker raise funds in Detroit for the establishment of an Astronomical Observatory. A meeting was held there a few days later, for the consideration of the project. Dr. Tappan and others spoke in favor of it, with the result that $7,000 were immediately raised, the Honorable Henry N. Walker, General Lewis Cass, Governor Henry Porter Baldwin, and Senator Z. Chandler, each subscribing $500, on condition that $10,000 be obtained within a year. Mr. Walker took a leading part in raising the funds, which eventually amounted to about $15,000, of which he gave $4,000. In honor of the citizens of Detroit, whose initial gifts made it possible, the Observatory was named "Detroit Observatory." The original building and instruments cost $22,000, of which $7,000 were supplied by the Board of Regents from University funds. Subsequently the citizens of Ann Arbor contributed $2,500 and those of Detroit $3,000, for needed improvements.

In the beginning it was the intention to buy a large telescope only and provide a building for it, but the liberality of the citizens of Detroit soon made it evident that the plan could be enlarged to include what was then regarded as the equipment of a complete Observatory.

When the funds were assured, Dr. Tappan acted upon the advice of his scientific friends and placed an order with Mr. Henry Fitz, of New York, for a refracting telescope, equatorially mounted, of not less than twelve inches aperture, at a cost of $6,000. At that time there were only two larger refractors in the world; namely, two fifteen-inch telescopes, one belonging to the Imperial Russian Observatory, at Pulkowa, and the other to the Harvard College Observatory. The refractor for Ann Arbor was the first large telescope constructed entirely in the United States, a country which has since become noted for the perfection and power of its astronomical instruments.

In March, 1853, while President Tappan was in Europe, mainly in the interest of the Observatory, Mr. Walker, acting in concurrence with him, made arrangements with Mr. George Bird, of New York, to superintend the construction of the Observatory building. Four acres of land, outside the city, on a hill overlooking the valley

of the Huron River, were purchased as a site, at a cost of $100 per acre.

During his trip abroad, President Tappan visited the principal observatories of Europe, and at Berlin had the good fortune to make the acquaintance of Professor Encke, and his young Assistant, Dr. Francis Brünnow. They took great interest in the new observatory and generously gave their counsel as to its equipment. Upon their advice a Meridian Circle was ordered from Pistor and Martins, and an astronomical clock from M. Tiede, both of Berlin. They constantly supervised the construction of these instruments, and when the clock was completed, they tested it thoroughly before it was shipped to the United States.

More important than the instruments which President Tappan obtained in Germany was the man whom he found in Berlin and persuaded to come to America to be the first Director of the Observatory. To this circumstance, more than to any other, is due the early fame of the Observatory and the wide influence which it has had on the development of Astronomy in the United States. When Dr. Francis Brünnow received this appointment he was already widely known, by reason of his numerous contributions to Theoretical and Practical Astronomy, and particularly for his able treatise on *Spherical Astronomy*. During his residence at Ann Arbor he continued his contributions to various astronomical periodicals, issued his tables of the minor planets *Flora* and *Victoria*, and, from 1858 to 1862, published the *Astronomical Notices*, a periodical which was designed as a medium for the prompt publication of the observations and scientific investigations of the officers of this and of other observatories.

Dr. Brünnow arrived in Ann Arbor, in July, 1854, about the time the Observatory building was completed, and within a few months he had installed the Meridian Circle and had begun to use it. There was some delay in getting the refractor in readiness for use. When first set up it was not entirely satisfactory and had to be dismounted to enable the constructor to make some necessary alterations. It was finally re-erected and made ready for use in December, 1857.

Dr. Brünnow was one of the small number of men, who at that early time gave the University its high character for scientific instruction. On his arrival he immediately planned advanced courses in Theoretical and Practical Astronomy, extending over two and a half years, in continuation of the elementary course which was then required of all students in the first semester of the Junior year. Notable among those who elected these advanced courses, soon after they were offered, were Cleveland Abbe, Asaph Hall, Sr., and James C. Watson.

In 1859, Dr. Brünnow accepted the position of Associate Director of the Dudley Observatory, in conjunction with Professor O. M. Mitchell, who, while retaining his position as Director of the Cincinnati Observatory, which he had founded, also assumed the direction of the new institution at Albany. It was the intention that the two observatories should work together in the formation of a large catalogue of stars, and to this end, it was to be Dr. Brünnow's task to bring into immediate activity the new Olcott Meridian Circle of the Dudley Observatory. After a year this work was interrupted, for the Board of Regents then urgently requested Dr. Brünnow to return to Ann Arbor, where he remained until 1863, when he resigned owing to the removal of President Tappan, whose son-in-law he had become. Two years later he became Professor of Astronomy in the University of Dublin and Astronomer Royal of Ireland, where he continued at the Dunsink Observatory his astronomical work, notably his investigations of stellar parallax. On account of failing health he resigned in 1874, and retired, first to Basel, then to Vevey, and finally to Heidelberg, where he died in August, 1891.

In 1863, James Craig Watson was elected Professor of Astronomy and Director of the Observatory. He had graduated at the age of nineteen, in the class of 1857, and in the following year had become Assistant in the Observatory. A year later, when Dr. Brünnow went to Albany, he was made Professor of Astronomy and placed in charge of the Observatory, without being given the title of Director. On Dr. Brünnow's return Professor Watson was transferred to the chair of Physics, a position which he held until Dr. Brünnow resigned. Then, upon his own ap-

plication, supported by the recommendations of B. A. Gould, Elias Loomis, William Chauvenet, Joseph Winlock, Benjamin Pierce, J. M. Gillis, and others, he was made the successor of his eminent teacher. Professor Watson remained at the head of the Observatory until 1879, when he resigned to become the Director of the new Washburn Observatory of the University of Wisconsin, where he died in the following year after an illness of only two days.

Very soon after he became director, Professor Watson began the preparation of a series of charts of the stars situated near the ecliptic, and during his administration this continued the principal observational work of the Observatory. The charts which he prepared, of which only two were completed, so laborious was their preparation by the methods employed, have become the property of the National Academy of Sciences, and are deposited with the Washburn Observatory.

The preparation of these charts was apparently undertaken with the expectation that they would aid in the discovery of additional minor planets, and this proved to be the case. Professor Watson discovered twenty-two of these bodies while he was Director of the Observatory at Ann Arbor. The first one, Eurynome (79), was found on September 14, 1863, only three weeks after he had been elected to this position. Four years passed before a second was detected. Then for a time they came in rapid succession; in 1868 six were added to the list, which was then an unprecedented feat. The complete list is as follows:

Minor Planets Discovered by Professor Watson.

NO.	NAME.	DATE OF DISCOVERY.
79	Eurynome	September 14, 1863
93	Minerva	August 24, 1867
94	Aurora	September 6, 1867
100	Hecate	July 11, 1868
101	Helena	August 15, 1868
103	Hera	September 7, 1868
104	Clymene	September 13, 1868
105	Artemis	September 16, 1868
106	Dione	October 10, 1868
115	Thyra	August 6, 1871
119	Althaea	April 3, 1872
121	Hermione	May 12, 1872
128	Nemesis	November 25, 1872
132	Aethra	June 13, 1873
133	Cyrene	August 16, 1873
139	Juewa	October 10, 1874
150	Nuwa	October 18, 1875
161	Athor	April 16, 1876
168	Sibylla	September 28, 1876
174	Phaedra	September 2, 1877
175	Andromache	October 1, 1877
179	Clytemnestra	November 11, 1877

Juewa (139) was discovered by Professor Watson, at Peking, China, while in charge of an expedition which had been sent there to observe the transit of Venus of 1874. The planet Aethra (132) has been lost. No observations of it have been obtained since the opposition at which it was discovered, 1873, and such observations as were obtained then have not proved sufficient for a satisfactory determination of the elements of its orbit.

The minor planets discovered by Professor Watson are in a sense endowed. He left with the National Academy of Sciences a sum of money for the promotion of astronomical science, and expressed the wish that provision be made for preparing and publishing tables of the motions of the planets which he had found. In compliance with this request the National Academy of Sciences has arranged for the performance of this work, and as a partial result, in 1910, published tables of the motions of twelve of these planets, prepared under the direction of Professor Armin O. Leuschner, of the University of California.

Professor Watson went on several astronomical expeditions, notably on eclipse expeditions to Iowa in 1869, to Sicily in 1870, to Wyoming in 1878, and on the transit of Venus expedition to China in 1874. While returning from China he visited India, Egypt, and Europe. Several weeks were spent in Egypt, where, at the invitation of the Khedive, he coöperated with the engineers of the Egyptian army in the first steps toward a geodetic survey of that country.

The eclipse of 1878 riveted Professor Watson's attention to the Intra-Mercurial problem. He believed in the existence of a major planet between Mercury and the sun; had corresponded with LeVerrier and obtained from him his predicted times of transit of such a body; and at Ann Arbor he had watched the sun in the hope of detecting such a transit. It is a matter of astronomical history that he supposed that he had recorded the place of one and possibly of two major planets at the time of the eclipse of 1878. During the remainder of his life he devoted much

time to preparations which he hoped would enable these supposed planets to be seen without an eclipse. He died suddenly while these preparations were still incomplete. More than thirty years have now passed. The planets have not been recovered, notwithstanding the extensive search made for them by photographic methods during several recent eclipses. Negative results only have been secured, but these have been of such weight that many astronomers have come to entertain grave doubts as to the existence of a large planet within the orbit of Mercury.

Professor Watson published several books, but his fame as an author depends chiefly upon his treatise on *Theoretical Astronomy,* which was prepared during the earlier years of his directorship, while he was devoting much time to the observation of the minor planets and the determination of their orbits. He was endowed in an unusual degree with the mathematical faculty, and seemed to play with problems which taxed the energies of others. He was a computer of remarkable skill and rapidity, as is attested by his making a complete determination of the elliptic elements of a planet's orbit at a single sitting. Early in the '60's he became interested in the reduction of the Washington Zones, which had been undertaken by Dr. Gould, and for several years he devoted much time to the computations of this work. In 1869 he became associated with Professor Benjamin Pierce, of Harvard University, in work designed to improve the lunar tables. For five years he was engaged in the comparison of the theories of Hansen and Pierce with observation, and in endeavors to simplify Hansen's tables, with results which, though satisfactory to himself, were never published and are now lost.

When Professor Watson resigned in 1879, to become the Director of the Washburn Observatory at Madison, Professor Mark W. Harrington was selected to fill the position which his withdrawal made vacant at Ann Arbor. Professor Harrington had graduated with the class of 1868, had been an Astronomical Aid in the reconnaissance work of the United States Coast Survey in Alaska, had filled for a time the Professorship of Astronomy and Mathematics in the Cadet School of the Foreign Office at Peking, China, and had taught various subjects in the University of Michigan.

On taking charge of the Observatory, Professor Harrington arranged for increased facilities for instruction in Practical Astronomy and for regular meteorological observations. The building for the Students' Observatory had been completed in 1879, and in the following year the instrumental equipment was obtained. The chief of these instruments were a six-inch refracting telescope, equatorially mounted, costing $1,800, and a three-inch transit instrument, costing $1,000.

Professor J. M. Schaeberle was at that time an Assistant in the Observatory, and he began to use the Meridian Circle in a new determination of the positions of the Struve double stars. He also undertook other observational work, and in the earlier part of this administration discovered two comets, the first in 1880 and the second in the following year. In 1888, Professor Schaeberlè went to California as an Astronomer in the Lick Observatory, and his place as Instructor in Astronomy was filled by the appointment of Professor W. W. Campbell, who had graduated from the University two years earlier, and who followed Professor Schaeberle to the Lick Observatory three years later. While an Instructor in the University of Michigan, Professor Campbell devoted much time to the observation of comets and to the determination of their orbits. It was during this period that his *Elements of Practical Astronomy* was prepared and first printed.

Professor Harrington's tastes had been strongly with the botanical and biological sciences, but on taking charge of the Observatory, he was diverted to other studies, and during his directorship he devoted much time to the consideration of meteorological questions. In 1884, he founded *The American Meteorological Journal,* then the only meteorological periodical published in the United States. In the beginning he was its sole editor, but later several meteorologists were associated with him in its editorial management, notably Professor A. Lawrence Rotch, the founder of the Blue Hill Meteorological Observatory.

The meteorological work of the United States Government was reorganized in 1891, by transferring it from the Department of War to the Department of Agriculture, and by placing it under a civilian director. Professor Harrington was called to Washington to reorganize this important branch of the public service. He assumed his duties, as first Chief of the Weather Bureau, on July 1, 1891, but his resignation as Director of the Observatory was not accepted until some months later. In the meantime the Observatory was left in the charge of Mr. William J. Hussey, then Instructor of Astronomy, who resigned in 1892, in order to accept a position in the new Leland Stanford Junior University.

Professor Asaph Hall, Jr., was selected as Professor Harrington's successor, and filled the office of Director from 1892 to 1905. During this time he was for the most part engaged in work with the Meridian Circle, making observations of Polaris for the determination of the value of the aberration constant. The results of these investigations have been printed in the *Astronomical Journal* and in the *Fourth Report of the Michigan Academy of Science.*

Professor Hall was graduated from Harvard University in 1882, and received the degree of Doctor of Philosophy from Yale University in 1889. From 1889 to 1892 he was Assistant Astronomer in the United States Naval Observatory, the institution to which he returned when he left Ann Arbor.

In 1905, Professor W. J. Hussey, who for nine and a half years had been an Astronomer in the Lick Observatory, was elected Director of the Observatory at Ann Arbor, and entered upon his duties in October of that year. Since then the Observatory has had the continuous support of the President and Board of Regents and many improvements have been made. In the winter of 1905-6, the Observatory Library and the Residence of the Director were reconstructed and enlarged; in 1906, the Observatory Shop was established and repairs to the instruments begun, notably the reconstruction of the six-inch and twelve-inch refractors; in 1907, the construction of the large reflecting telescope was undertaken; in 1908, the Students' Observatory was moved to a new location and a new building added to the original Observatory, having a dome for the large reflecting telescope, clock and class rooms, laboratory, photographic dark rooms, offices, etc.; in 1909, seismographs of modern type were installed in the new building; and in 1911, the large reflecting telescope was completed and spectroscopic work with it begun. Moreover, in 1910, the Observatory Grounds were extended toward the east, by the addition of twenty-six acres of land, the gift of Mr. R. P. Lamont, of Chicago, who graduated as Civil Engineer with the class of 1891. Also, in 1910, the construction of the twenty-four-inch Lamont Refractor was begun, an instrument which is intended for use in the Southern Hemisphere, for work on double stars and for other observations.

In 1911 an arrangement was made with the Universidad Nacional de La Plata by which Professor Hussey became the Director of La Plata Observatory, while still retaining the directorship of the Observatory of the University of Michigan, his time being divided between the two institutions. At this time Professor Ralph H. Curtiss was made Assistant Director of the Observatory at Ann Arbor, in full charge during the absence of Professor Hussey. Dr. Curtiss received the degree of Doctor of Philosophy from the University of California in 1905. He was a Fellow at the Lick Observatory from 1901 to 1905 and Astronomer in the Allegheny Observatory from 1905 to 1907, when he came to the University of Michigan.

The University of Michigan was one of the first in the United States to give advanced instruction in Theoretical and Practical Astronomy, and the officers of the Observatory have always regarded this work as an important part of their duties. As a result of this consistent policy, extending over more than half a century, many important astronomical positions have been filled by those who have studied here, and the work done by these men and by the students whom they have trained in other institutions, has had a wide influence on the development of Astronomy in this country.

The following American Astronomers have been students in the University of Michigan.

James C. Watson, A.B. 1857. Director of the Observatory at Ann Arbor from 1863 to 1879. Discoverer of twenty-two minor planets.

Asaph Hall, Sr., 1856-57. For many years Astronomer in the United States Naval Observatory. Discoverer of the Satellites of Mars.

Cleveland Abbe, Graduate student in Astronomy, 1858-59. Director of the Cincinnati Observatory, 1868-73. Founder of the United States Signal Service. Meteorologist in the Signal Service and Weather Bureau since 1871.

William W. Payne, 1863-64. Director of the Goodsell Observatory of Carleton College, 1871-1908. Director of the Elgin Observatory since 1908. Founder of *The Sidereal Messenger* and of *Popular Astronomy*.

Mark W. Harrington, A.B. 1868. Director of the Observatory at Ann Arbor, 1879-92. Chief of the United States Weather Bureau, 1891-96.

W. F. M. Ritter, A.B. 1871. Sometime Assistant in the United States Naval Observatory and Nautical Almanac Office.

R. S. Woodward, C. E. 1872. Astronomer on U. S. Transit of Venus Commission, 1882--84. Astronomer, U. S. Geological Survey, 1884-90. President of the Carnegie Institution at Washington since 1905.

M. B. Snyder, A. B. 1872. Director of the Philadelphia Observatory.

Otto J. Klotz, C. E. 1872. Astronomer in the Dominion Observatory, Ottawa, Canada.

C. L. Doolittle, C. E. 1874. Director of the Sayre Observatory of Lehigh University, 1875-95. Director of the Flower Observatory of the University of Pennsylvania since 1895.

J. M. Schaeberle, C. E. 1876. Assistant, Instructor, and Acting Professor in the Observatory at Ann Arbor, 1878-88. Astronomer in the Lick Observatory, 1888-98; Acting Director of the Lick Observatory, 1897-98.

George C. Comstock, Ph.B. 1877. Professor of Astronomy in the Ohio State University, 1885-87. Director of the Washburn Observatory of the University of Wisconsin, since 1887.

Mary E. Byrd, A.B. 1878. Director of Smith College Observatory, 1887-1906.

Edward Israel, A.B. 1881. Astronomer on the Greely Polar Expedition.

W. W. Campbell, B.S. (C.E.) 1886. Instructor in Astronomy in the University of Michigan, 1888-91. Astronomer in the Lick Observatory since 1891; Director of the Lick Observatory since 1901.

A. O. Leuschner, A.B. 1888. Director of the Students' Observatory of the University of California since 1898.

W. J. Hussey, B.S. (C.E.) 1889. Astronomer in the Lick Observatory, 1896-1905. Director of the Observatory at Ann Arbor since 1905. Director of La Plata Observatory, Argentina, since 1911.

A. L. Colton, Ph.B. 1889. Assistant Astronomer in the Lick Observatory, 1892-97.

H. L. Rice, 1889-91. Assistant Nautical Almanac Office, 1892-1902. Astronomer in the Naval Observatory, 1902-07. Professor of Mathematics in the U. S. Navy since 1907.

J. Robertson, B.S. 1891. Assistant in the United States Nautical Almanac Office since 1892.

H. D. Curtis, A.B. 1892. Astronomer in the Lick Observatory.

J. C. Hammond, B.S. (M.E.) 1894. Assistant Astronomer in the United States Naval Observatory.

W. M. Hamilton, A.M. 1896. Assistant Nautical Almanac Office.

S. D. Townley, Ph.D. 1897. Sometime International Latitude Observer at Ukiah. Assistant Professor of Astronomy in Leland Stanford Junior University.

O. M. Leland, B.S. (C.E.) 1900. Professor of Astronomy in Cornell University. Astronomer on demarcation of Alaskan boundary.

Harriet Bigelow, Ph.D. 1904. Director Smith College Observatory.

Frank D. Urie, A.B. 1910. Astronomer in Elgin Observatory.

LOCATION.

The Observatory grounds originally included one city block, about four acres, situated in a northeasterly direction from the University, at a distance of one-half mile from the center of the Campus. By the gift of Mr. Robert P. Lamont, of Chicago, in 1910, these grounds were enlarged by an addition of twenty-six acres, lying east of the original grounds and connecting them with a large City Park and with the University Botanical Gardens.

The Observatory grounds are at the northeastern limit of the city of Ann Arbor. The Huron River is in this direction, at a distance of about one-half of a mile from the Observatory. It runs in a southeasterly direction, at the bottom of a narrow valley, along whose sides rise rolling hills, to an elevation of from one to two hundred feet, formed by glacial action at the time the last ice sheet covered this region. The Forest Hill Cemetery occupies many acres, a short distance southeast of the Observatory, between it and the southerly extension of the city. It has many large forest trees, which shelter the Observatory from the lights in this direction. The Women's Athletic Field, with its well-wooded ten acres, joins the original Observatory grounds on the south.

PLATE II. THE DETROIT OBSERVATORY FROM THE NORTHEAST
1910

PLATE III. THE DETROIT OBSERVATORY FROM THE NORTHWEST

1910

By reason of the nearness of the River, and the character of the topography to the north and east, and the situations of the City Park, the Botanical Gardens, the Forest Hill Cemetery, and the Athletic Field, the Observatory is unusually well protected toward the north, east and south, the directions in which most of its observational work is done. Moreover, it is near the University and readily accessible to students, so near that they are able easily to take advantage of the facilities afforded for training in Practical Astronomy.

The latitude and longitude of the Observatory, referred to the center of the Meridian Circle, are given in the *American Ephemeris and Nautical Almanac,* and in other similar publications, as follows:

Longitude = $5^h 34^m 55^s.19$ West of Greenwich.
Latitude = $+ 42° 16' 48''.0$.

A telegraphic longitude connection was made in 1861 with the Litchfield Observatory of Hamilton College which had been similarly connected with Harvard Observatory in 1859. The resulting longitude difference, Ann Arbor-Harvard, proved to be + 50m 24.21s ± 0.05s. This difference in combination with the longitude of the Harvard Observatory (4h 44m 30.98s ± 0.04s) as determined through the cable observations of 1866, 1870 and 1872, probably yielded the above value for the longitude of the Detroit Observatory. A second longitude connection with the Harvard Observatory was made in 1869. And on two occasions connections were established with the U. S. Lake Survey Station in Detroit.

The above value of the latitude has apparently come from an approximate value published by Dr. Brünnow, shortly after the establishment of the Observatory. Later investigations have given somewhat larger values. Thus, from observations which he made in 1886-87, with the Three-Inch Transit Instrument, as stated in connection with the description of that instrument, Dr. Ludovic Estes obtained + 42° 16′ 48″.66, as the latitude of the Meridian Circle. From his observations of Polaris, with the Meridian Circle, Professor Hall stated, in 1902, that the latitude could be taken provisionally at + 42° 16′ 48″.8. From direct and reflected observations of twenty-six circumpolar stars, made with the Meridian Circle, in the years 1901, 1902, and 1903, Miss Harriet W. Bigelow obtained + 42° 16′ 48″.76. All of her values were in good agreement; the smallest was 48″.42, and the largest 49″.35.

BUILDINGS.

The original Observatory building was completed in the summer of 1854. It then consisted of a central square portion, thirty-three feet on a side, surmounted by the dome for the twelve-inch telescope; and two wings, each nineteen by twenty-nine feet, the one on the east side having a room for the meridian circle, and that on the west side a room for the office of the Director and the Observatory Library. A residence for the Director was added, at the west side of this building, in 1868, and considerably enlarged and improved in 1905-6. It connects with the Observatory, through the Library.

During Professor Watson's administration, the Students' Observatory was erected near the main building, where it remained until 1908, when, to clear the site for the dome of the large reflecting telescope, it was removed to a new situation, about three hundred feet west of the principal building. Professor Watson also obtained another small building, to provide quarters for the meteorological assistants and a "computing room" for the students in Practical Astronomy. In 1906, the Observatory Shop was established in the basement of this building, which is entirely above ground, and, in 1908, when additional shop space became imperative in the course of the construction of the large reflecting telescope, this basement was extended toward the west, for the accommodation of the work then in hand.

In anticipation of the transit of Mercury in 1878, a small building was erected to serve for the photographic operations at that time in accordance with the program adopted by the American observers. This building was placed in the meridian of the three-inch transit instrument, about sixty feet south of it, with a pier just outside the transit room for the heliostat and camera lens, and one just within the photographic house for the reticle plate and photographic plate holder. The heliostat and optical parts which had been provided for this work were not a part of the

equipment of the Observatory. They were loaned by the Federal Government.

This building was used again, in 1882, in a similar manner, at the last transit of Venus. On account of clouds, these observations were only partially successful.

In 1910, this building was removed to the vicinity of the Shop and is now used as an adjunct to the Shop for storage purposes.

What is now the principal building of the Observatory was begun in 1908 and completed in the following year, with the exception of such parts of the dome as could not be finished until the large reflecting telescope was installed. It joins the meridian circle room on the east in the same manner that the residence joins the Library on the west, and has a frontage of forty-four feet on the north, and a length of one-hundred and twelve feet from north to south. It terminates at the south end in a circular wall, forty-three feet high, which supports the forty-foot dome of the large reflecting telescope. The building has two stories, and a basement which is practically above the level of the ground. On the main floor are the offices of the Director and Secretary, a class room, clock room, vault, and entrance and main halls. On the second floor are three offices and two dark rooms. The basement contains rooms for laboratory, office, seismographs, batteries, coal and furnace. The building is well provided with closets for the storage of supplies and for other purposes.

The clock room has brick walls on all sides, and is completely enclosed within the building. It has a window opening into the main hall, closed by two thicknesses of plate glass, with an air space between, set in a single sash. The clock piers have concrete foundations, bedded in hard clay, at a distance of about ten feet below the original surface of the ground. One of the piers is of brick, set in cement; the other is of brick to the level of the clock room floor and from that level a monolith of limestone.

One of the clocks is visible from the hall, and electrical connections are made at the switch-board near the window. The battery room is directly below the switch-board, and a conduit runs from the switch-board to the attic, so arranged that the wiring is readily accessible.

THE TWELVE-INCH TELESCOPE.

The Twelve-Inch Telescope. This telescope was originally constructed by Henry Fitz, of New York, and erected in its present position in December, 1857. It has a clear aperture of twelve and one-fourth inches and a focal length of two hundred inches. At the time of its completion it was one of the large telescopes of the world; the only larger refractors then in existence were the fifteen-inch telescopes of the Pulkowa and Harvard Observatories.

The region about Ann Arbor is covered with glacial drift, consisting of a mixture of clays, sand, and gravel, many feet in thickness. At the Observatory the superficial layers are hard clay, with occasional streaks of fine sand, and the sub-piers of the instruments are set in these clays. The sub-pier for the twelve-inch telescope is a frustum of a circular cone, built of brick, having its base about ten feet below the original surface of the ground, and rising to the level of the dome floor, where it is capped with a large stone which receives the vertical monolith, that forms the pier of this instrument. The center of motion of the telescope is thirty-three feet above the level of the ground immediately outside the building, and in all directions from the building the ground falls away rapidly to lower levels, giving an effective elevation greater than would be obtained from the buildings alone.

The Original Mounting. The original mounting was similar to those of most of the large refractors of its period. Its pier is a limestone monolith, having its upper surface cut to the inclination of the latitude of the place, and carrying at its top an iron base for supporting the bearings of the polar axis. This base also carries the devices for adjustment in altitude and azimuth.

The original tube was made of pine, with a veneer of polished mahogany, and was supported at its center in a cast-iron cradle, fitted to the upper end of the declination axis. Attached to this cradle and to the upper end of the tube were long wooden rods, which, extending to the eye end, were intended for moving the telescope and for carrying the counter-weights. Owing to the flexibilty of these rods they had the disadvantage

of setting the telescope in vibration when it was moved from one position to another.

The movement of the driving clock was controlled by a short oscillating pendulum, whose effective length could be altered to give different rates. The mechanism, however, was too light for the work it had to do, and in consequence the clock proved inefficient and was seldom used.

The worm wheel and the graduated circle in right ascension were attached to the lower part of the polar axis, and the operations of clamping and unclamping in right ascension were effected by throwing the worm in and out of gear. The slow motion in right ascension operated directly upon the worm shaft, by means of a telescoping rod, which could be carried to the eye end of the instrument.

The graduated declination circle was attached to the lower end of the declination axis and the clamp and slow motion in declination were connected with this circle. Owing to these arrangements it was necessary to leave the eye end of the instrument to clamp or unclamp, either in right ascension or in declination, and the slow motions by means of rods not carried upon the instrument itself were inconvenient and inefficient.

The Original Micrometer. The original micrometer is of the Fraunhofer pattern. It has a graduated circle, about four and one-half inches in diameter, divided to quarter degrees, and read by means of verniers to single minutes. The scale is small and the divisions fine, and consequently it is not easy to read under such conditions of illumination as exist when observations are being made.

The micrometer threads are carried on frames moved by screws at either end of the box, but only one of these has a graduated head. Hence, there is no constant position for coincidence of wires, which is not only inconvenient but also a possible source of error in making and reducing the observations.

No observations have been made with this micrometer in recent years. It is regarded as fit for museum purposes only. The value of one revolution of the screw, as derived from the pitch of the screw and the focal length of the telescope is about $11''.15$.

Alterations. In 1907, this telescope was dismounted and many old parts discarded and new ones made to take their places. New parts were substituted as follows:

Tube of sheet steel; draw-tube of bronze, with provision for carrying eye-pieces and micrometer directly, and other pieces of apparatus when these are removed; driving clock of the usual double conical pendulum type; worm and worm wheel; clamps and slow motions in right ascension and declination, so arranged that they may be operated from the eye end of the telescope; coarsely graduated circles; and electric illumination for the micrometer and graduated circles.

With the exception of the micrometer, the new parts were all made in the Observatory Shop, by the Observatory Instrument Makers, Messrs. E. J. Madden, E. P. Pegg, and H. J. Colliau.

Filar Micrometer. In 1907, a new micrometer for this telescope was received from The Warner & Swasey Company, of Cleveland, Ohio. It was beautifully made, but on examination was found to need a number of alterations to give it increased efficiency.

The original graduations had a width of about 0.002 of an inch and were sharply defined when seen under a microscope, such as those employed in reading the graduated circles of a meridian circle. But they were not sufficiently distinct to be read quickly and accurately with the naked eye, under such conditions of illumination as ordinarily obtain in the use of an equatorial telescope. By experiment it was ascertained that graduations having a width of about 0.007 of an inch would be much better, and on returning the circle to the makers they kindly increased the graduations to this width.

Several alterations in the micrometer have been made in the Observatory Shop, by Mr. H. J. Colliau. To secure better illumination of the wires the illuminating apparatus furnished by the makers has been replaced by a simpler and more efficient construction. Teeth have been cut in the circumference of the circle and spur gears fitted for giving the micrometer a quick motion in position angle. Such motion is essential to satisfactory work in the measurement of double stars and for other determinations of position angle.

Several determinations of the value of one revolution of the screw of this micrometer have been

made, some by the method of measuring the difference of the declinations of known stars, and others by the method of transits of circumpolar stars. The results have all been in good agreement. From transits of Polaris, made under excellent conditions, on October 17, 1910, I obtained the following value of one revolution:

$$R = 20''.565 \pm 0''.0001.$$

This determination depends upon transits observed at every half revolution of the screw from the second to the eighty-eighth revolution inclusive.

Dome and Shutter. This is the dome originally constructed to cover this instrument, but modified as stated below. It is hemispherical, with an inside diameter of twenty-one feet, and with a slit thirty inches wide, extending from the level of the center of motion of the telescope, which is eleven feet two inches above the floor, to a point somewhat beyond the zenith.

The dome has a strong wooden frame, supported on a cast-iron base. This frame is covered on the outside, first with wood and then with heavy tin plate, painted white; and on the inside with a thin sheathing of painted wood.

The original shutter for covering the slit moved between grooves, up, over the dome, and down on the side opposite the slit. This was a highly incommodious arrangement and difficult of operation.

The dome was originally supported on cannon balls, which ran in grooves provided for them in the castings, below, on the wall, and above, at the base of the dome. No provision was made for keeping the balls at uniform distances apart and whenever they rolled together the dome could not be moved until the balls were readjusted.

The original observing chair was carried around with the dome and no means were provided for varying its position, forward and back, for the accommodation of the observer.

In 1890, improvements were made converting the dome into one of modern effectiveness and convenience. At that time the present shutter and mechanism for turning the dome were supplied by The Warner & Swasey Company. At the same time a new observing chair of the Burnham-Hough pattern was installed in place of the old one. This chair, in turn, was superseded, in 1907, by a similar one of lighter and more convenient construction.

The present shutter opens horizontally, by a single pull upon the handle attached to the opening cable; and is closed by a single pull upon the handle attached to the closing cable.

The dome is now mounted on a live ring and is easily operated, by hand, by means of an endless rope passing over a sheave. An endless steel cable forms a belt passing around a circular angle iron, attached to the inside of the dome near its base, and over a series of sheaves connected with that carrying the endless rope.

The live-ring consists of eleven rollers, of three wheels each, with their supporting blocks and bearings, guide wheels and connecting rods. These wheels are about seven inches in diameter. The two outside wheels of each roller run upon the planed cast-iron tracks that rest upon the wall; and the middle wheel of each roller receives the weight of the dome, through the planed track upon the lower side of the cast-iron base-plate of the dome.

THE MERIDIAN CIRCLE.

The Meridian Circle was the gift of Mr. Henry N. Walker, of Detroit, at the time of the foundation of the Observatory. It was constructed by Pistor & Martins, of Berlin, and bears the date, 1854. It is mounted in the east wing of the original building, a room whose length in the north and south direction is 26 feet 5 inches, width, 17 feet 8 inches, and height, 13 feet 4 inches. There are windows at the north and south sides of the room, closed by sliding shutters, so arranged that they may be used in connection with the slit to give an opening from the horizon on the north to that on the south. The slit is thirty inches in width.

The foundation walls of the building are of stone and the walls themselves of stuccoed brick. The piers for the instrument and collimators are of brick below the level of the floor, and limestone monoliths above this level. The Meridian Circle is mounted between the faces of two of these monoliths, and the counterweights are supported on the tops of them. The pier below the level of the floor is connected and carries at its center

the support for the artificial horizon, used for nadir observations.

The objective has a clear aperture of 6.3 inches and a focal length of 96.8 inches. About 1902, it was investigated in the Physical Laboratory by Professor Harriet W. Bigelow, now of Smith College Observatory. She examined the structure of the glass by means of Nicol prisms at conjugate foci, and found that the lens, instead of being entirely dark for perpendicular position of the prisms, shows irregular light portions extending toward the center, due to irregular polarization in the glass. She says: "Practically, however, the lens gives excellent star images for meridian work, *i. e.*, small, round disks, of uniform size across the field of view."

The graduated circles are thirty-seven and one-half inches in diameter. The one on the clamp side is divided to 10′ and the other one to 2′. Each of the circles is read by four microscopes, magnifying sixteen diameters, and reading to tenths of seconds of arc. Each microscope is furnished with two pairs of threads separated one and a half revolutions, so that readings upon consecutive divisions of the fine circle may be made by an additional half turn of the micrometer. screw. The microscopes are carried on a ring in such a manner that the distances between them may be altered. The minimum distance apart at which they may be set is about 15°.

About 1893 a Repsold transit micrometer was obtained for this instrument. In addition to the movable right ascension thread and the two usual horizontal threads, it is provided with twenty-five transit threads, arranged in groups of five. There is no movable thread in declination. Settings in this coördinate are made by means of the tangent screw of the instrument.

In the account of his determination of the value of the aberration constant, published in the *Proceedings of the Michigan Academy of Sciences*, for 1904, Professor Asaph Hall, Jr., states that the value of one revolution of the micrometer screw of the Meridian Circle is approximately $3^s.640$. A value in complete agreement with this was obtained by Mr. George A. Lindsay, from observations of transits of Polaris, made on September 7, 1906. He observed 138 transits of the star over the movable thread, during its passage through the field of view, and from these observations he derived the following value of one revolution:

$$R = 54''.610 \pm 0''.007,$$

or

$$R = 3^s.641.$$

The temperature at the time of Mr. Lindsay's observations was 82° Fahrenheit.

The collimators have clear apertures of two inches and focal lengths of about two feet. They are mounted on piers at the north and south ends of the room, in the usual manner, with their lines of sight on the level of the axis of the Meridian Circle.

Dr. Brünnow states that when the Meridian Circle arrived at Ann Arbor, the circle on the side of the clamp was slightly bent, and that it was used merely for setting the instrument, and that the other one only was used for reading zenith distances. He determined the periodic and accidental errors of the latter circle, at intervals of five degrees, and published the details of his investigation in the *Astronomical Notices*. These results are summarized in the accompanying table. The measured errors for every fifth degree are given in the column headed I. These include not merely the accidental division errors, but also the systematic errors arising from the eccentricity of the circle and the departure of the pivots from circular form. The eccentricity produces terms of the form

$$a + b \cos x + c \sin x.$$

By the aid of the values given in column I, Dr. Brünnow found the following expression for the error due to eccentricity:

$$+ 4''.044 - 3''.835 \cos x + 1''.561 \sin x.$$

If the errors due to the eccentricity of the circle be calculated for every fifth degree, by means of this formula, and subtracted from the corresponding errors given in column I, the results given in column II will be obtained. These results have two regular periods; one depending upon the double angle, and the other having itself a period of ten degrees. They are represented by the following expression:

$$- 0''.603 \cos (2x + 74° 20') - 0''.23 \cos 36x.$$

The first term shows that the circle has a small eccentricity, and the latter probably arises from the manner in which the graduations were made.

If these periodic errors are computed by this formula for every fifth degree and subtracted from the corresponding values in column II, the results given in column III will be obtained. So far as this investigation goes, these may be regarded as the accidental errors of graduation. The probable error in the position of any line is ± 0″.38, and the probable error of the mean of four lines is ± 0″.19.

READING	I	II	III
0°	0″.00	—0″.21	+0″.18
5	+1 .51	+1 .15	+0 .98
10	—0 .31	—0 .85	—0 .67
15	+1 .00	+0 .26	—0 .12
20	+0 .67	—0 .30	—0 .32
25	+1 .76	+0 .53	—0 .04
30	+1 .30	—0 .20	—0 .39
35	+3 .00	+1 .20	+0 .48
40	+1 .86	—0 .25	—0 .57
45	+3 .36	+0 .92	+0 .11
50	+3 .20	+0 .42	+0 .05
55	+4 .31	+1 .19	+0 .36
60	+3 .73	+0 .25	—0 .10
65	+5 .11	+1 .27	+0 .49
70	+4 .47	+0 .27	0 .00
75	+5 .91	+1 .35	+0 .69
80	+5 .10	+0 .19	+0 .07
85	+6 .44	+1 .18	+0 .69
90	+5 .46	—0 .14	—0 .07
95	+6 .69	+0 .76	+0 .47
100	+5 .26	—0 .99	—0 .71
105	+6 .78	+0 .24	+0 .16
110	+5 .72	—1 .10	—0 .62
115	+6 .58	—0 .50	—0 .39
120	+6 .45	—0 .86	—0 .21
125	+6 .81	—0 .71	—0 .45
130	+7 .18	—0 .52	+0 .25
135	+7 .15	—0 .71	+0 .36
140	+7 .18	—0 .80	+0 .03
145	+6 .82	—1 .26	—0 .89
150	+7 .46	—0 .69	+0 .12
155	+8 .66	+0 .48	+0 .80
160	+7 .73	—0 .45	+0 .28
165	+8 .07	—0 .08	+0 .12
170	+7 .69	—0 .40	+0 .18
175	+8 .56	+0 .56	+0 .59
180	+7 .50	—0 .38	+0 .01
185	+7 .67	—0 .06	—0 .23
190	+7 .97	+0 .42	+0 .60
195	+6 .77	—0 .57	—0 .95
200	+7″.05	—0″.06	—0″.08
205	+6 .91	+0 .05	—0 .52
210	+6 .81	+0 .23	+0 .04
215	+7 .33	+1 .04	+0 .32
220	+6 .00	—0 .02	—0 .30
225	+7 .65	+2 .00	+1 .19
230	+5 .81	+0 .50	+0 .13
235	+6 .91	+1 .95	+1 .12
240	+4 .46	—0 .15	—0 .50
245	+4 .93	+0 .68	—0 .10
250	+3 .39	—0 .50	—0 .77
255	+4 .23	+0 .70	+0 .04
260	+3 .09	—0 .08	—0 .20
265	+2 .19	—0 .63	—1 .12
270	+2 .20	—0 .28	—0 .21
275	+1 .18	—0 .97	—1 .26
280	+1 .93	+0 .09	+0 .37
285	+1 .62	+0 .08	0 .00
290	+1 .36	+0 .09	+0 .57
295	+1 .67	+0 .66	+0 .77
300	+0 .58	—0 .19	+0 .46
305	+0 .83	+0 .26	+0 .52
310	—0 .04	—0 .42	+0 .35
315	—0 .48	—0 .71	—0 .36
320	—0 .43	—0 .53	+0 .30
325	—0 .42	—0 .42	—0 .05
330	—0 .05	+0 .01	+0 .82
335	—0 .78	—0 .69	—0 .37
340	—0 .49	—0 .40	+0 .33
345	—1 .31	—1 .25	—1 .05
350	+0 .13	+0 .13	+0 .71
355	—1 .66	—1 .76	—1 .73

Miss Bigelow determined the amount of flexure, by combining reflected and direct observations, using the following formulae:

W. D. $\zeta = z_1 + a \cos z + b \sin z - (180° + N) + a,$

W. R. $180° - \zeta = z_2 - a \cos z + b \sin z - (180° + N) + a,$

E. D. $360° - \zeta = z_3 + a \cos z - b \sin z - (180° + N) + a,$

E. R. $180° + \zeta = z_4 - a \cos z - b \sin z - (180° + N) + a,$

where E and W denote respectively clamp east and clamp west.; D, direct; R, reflected, and N the nadir reading. She found the coefficient of cosine flexure to be 1″.694, and that of sine flexure, 0″.117. "In the case of clamp west the circle readings increase from the zenith toward the north and the formula for the flexure correction is

$$\zeta = z + 0''.162 - 1''.694 \cos z + 0''.117 \sin z - 1''.694."$$

The Chronograph made by Fauth & Company is now located in the entrance hall of the new building, about midway between the clock room and the meridian circle room.

THE LARGE REFLECTING TELESCOPE.

In June, 1906, the Board of Regents set aside the sum of $15,000, as an initial appropriation toward the construction of a large reflecting tel-

PLATE IV. THIRTY-SEVEN AND ONE-HALF INCH REFLECTOR

escope. In doing so they adopted the plan of having the instrument designed at the Observatory and as largely as possible constructed in the Engineering and Observatory Shops. In each of the three succeeding years, as was planned, additional small appropriations were made for continuing the work, and on the completion of the telescope, in May, 1911, there had been expended upon it and its accessories the aggregate sum of about $24,000. This aggregate includes the cost of designing and constructing the mounting, the special tools required in the shop for the work, optical parts, stellar spectrograph and measuring engine, and the various auxiliary instruments and accessories which are necessary for the successful operation of the instrument.

The Large and Small Mirrors.

The optical parts of the large reflecting telescope were ordered from The John A. Brashear Company, Allegheny, Pennsylvania, in August, 1906, and they were finished and delivered in Ann Arbor in December of the following year.

When the large mirror was ordered it was specified that it should have a clear aperture of at least thirty-six inches, and a focal length of about 19.1 feet; that it should be made of an excellent disk of well-annealed crown glass, not necessarily the grade of crown glass that is used for objectives, but the best quality of crown that is used for large mirrors; that the disk should be about six inches in thickness, and that it should have a central aperture five inches in diameter, so that the telescope could be used in the Cassegrain form of construction. It was further specified that the finished mirror should be parabolic and free from zones, showing no sensible errors under rigorous tests, and that the makers should provide the means of conducting the tests in a satisfactory manner, not only by laboratory methods, but also if required by observations upon stars.

The glass was made at St. Gobain, France, and in its rough state the disk weighed about 650 pounds. It was somewhat larger than specified, and in working it the opticians left it as large as possible. Owing to these circumstances the finished telescope has a larger clear aperture than was first planned. The mirror has an outside diameter of 37⅝ inches. The front edge is slightly beveled, and the diameter of the silvered surface is 37⅜ inches. We commonly speak of the mirror as having a diameter of 37½ inches.

A central hole about three inches in diameter was cast in the disk, and in the course of the work at Allegheny, this was enlarged to the required diameter of five inches. This was in many respects a critical operation, for, in so large a disk, the cutting of a central hole relieves the interior stresses to such an extent that the disk is liable to go to pieces unless it is exceptionally well annealed.

There are three secondary mirrors, each about ten inches in diameter. One of them is plane and the other two are hyperbolic. The hyperbolic mirrors have been finished to such curvatures that when used in connection with the large parabolic mirror, the combination has an equivalent focal length of sixty feet. The position of the Cassegrain focus is about two feet back from the front surface of the large mirror, a position which is very convenient for the spectroscopic work.

Type of Mounting.

The mounting is a modification of the English type. The polar axis is supported at its two ends on separate piers, and the declination axis intersects it a foot below its center. This form of mounting allows the instrument to pass the meridian without reversal and also permits all parts of the sky to be reached with as much facility as with the usual form of equatorial mounting.

The space between the north and south piers is sufficient to permit the free passage of a single prism spectroscope, when attached to the instrument, at all hour angles at which work would be done, up to declination $+60°$.

It is common to work with the tube and spectroscope under the polar axis. The eye-end is then near the floor for all ordinary hour angles, and this is convenient for the observer, since it requires very little movement on his part while making the observations.

The Polar Axis.

The polar axis is sixteen feet long and consists essentially of three castings, two steel shafts, and

two relieving roller bearings, all so rigidly fastened together as practically to form a single piece. The central casting is cubical, and was carefully machined on opposite sides to receive the machined bases of two conical castings, which are firmly attached to it. The relieving roller tires are made of tool steel, and when machined they were pressed upon the upper and lower steel shafts to their designated positions. The smaller ends of the conical castings were bored out and the steel shafts forced into them under heavy hydraulic pressure. After the parts were assembled, the polar axis was finished by grinding all the bearing surfaces to their specified dimensions, in a large lathe, at a single centering. These bearing surfaces include the upper and lower bearings of the polar axis each 6.75 inches in diameter; the relieving roller tires, 9.00 inches in diameter; the bearing for gears on the upper polar axis shaft, 6.80 inches in diameter; and the bearing for the worm wheel on the lower polar axis shaft, 9.25 inches in diameter. The parts of the polar axis have not been separated since these bearings were ground.

The polar axis turns in babbitted boxes, and has relieving rollers near each end, designed to carry the greater portion of the weight. The thrust of the polar axis is taken by a roller thrust bearing, which is supported on an adjustable block.

The two ends of the polar axis are supported on separate piers, each of which is provided with screws for the adjustment of the instrument in altitude and azimuth. When such adjustments are made the alignment of the polar axis bearings would be destroyed if provision were not made for corresponding changes in the directions of the bearings themselves. This is effected by having the bearings in blocks, the outsides of which are finished spherical surfaces. These blocks rest in others, having corresponding concave spherical surfaces, and are held in place in such a manner that they may respond to any changes which may be impressed upon the polar axis in the course of the adjustment of the instrument.

The Declination Axis.

The declination axis is made from a steel forging, and in its finished form it is about eight inches in diameter and nearly seven feet in length. Its diameter at the upper end is enlarged by a flange to eighteen inches, by means of which it is attached to the central casting of the telescope tube.

The declination axis passes centrally through the cube of the polar axis, and its lower end and the counterweights are supported by a conical casting attached to this cube.

The declination axis is provided with roller shaft bearings and with roller thrust bearings at its upper and lower ends. The thrust bearings are so arranged that they take the thrust in both directions with equal facility.

The declination axis has a longitudinal hole, three and a half inches in diameter, bored throughout its length. This is for the passage of the shafts for the operation of the clamp and slow motion in right ascension.

The Tube.

The tube consists of a central section, connected with the declination axis, which carries the ring for the declination clamp and the graduated declination circle; a lower heavy cylindrical casting, to which are attached the cell for the mirror, the carrying frame for the spectroscope, the auxiliary counterweights, the brackets for the clamps and slow motions, and the terminals of the electrical connections; an upper section made of boiler plate riveted together and strengthened by heavy internal bronze rings; and, finally, a short Newtonian section, fitted to the upper end of the tube in such a manner that it may be rotated about the axis of the instrument and clamped in any position.

The central section of the tube is built upon a heavy square casting, to which are fastened two strong cast steel rings, connected by a cylindrical piece of thick boiler plate. By this arrangement this section of the tube is flat on one side, and it is upon this flat side that the cover to the mirror is hinged, as described elsewhere.

Worm Wheel.

The worm wheel is situated near the lower end of the polar axis, with the worm mounted on the north face of the upper south pier casting. The wheel itself is made of cast iron, with an inserted bushing of bronze as the bearing sur-

face, and with an attached ring of bronze upon which the teeth are cut. The diameter of the wheel is very nearly 40.5 inches. It has three hundred and eighty teeth, single thread, three pitch, left hand.

The thrust of the worm wheel is taken by a ball thrust bearing, which encircles the polar axis just below the wheel. The balls are one-half inch in diameter and run between hardened and ground steel plates. The worm wheel was made by the Brown & Sharpe Mfg. Co., of Providence, Rhode Island, and worm by Mr. Emile Colliau, Instrument Maker at the Observatory. The worm is arranged to run continuously in oil.

Driving Clock.

The driving clock is of the usual double conical pendulum type, driven by a weight, which is automatically wound by means of an electric motor. The pendulum system is supported on ball bearings and revolves in five-sixths of a second. The principal axes are carried on roller bearings, running in hardened and ground steel cases.

Quick Motions.

Quick motions in right ascension and in declination have been provided, which are operated by means of hand wheels placed at a convenient height on the south face of the north pier, and also from the top of this pier. The latter provision was made, having in mind the possibility of the use of the instrument in the Newtonian form, in which case an additional observing floor would probably be erected at about the level of the center of motion.

The setting scale for hour angles is placed on the south face of the north pier, near the quick motion handles, and the declination circle can ordinarily be read without difficulty from the same position. This position of the setting handles has, therefore, been found very convenient.

The right ascension quick motion is thrown out of gear by means of a clutch, which is also operated from the south face of the north pier. This clutch throws out of action a long train of gears, including the so-called "jack-in-the-box" system, which is mounted in the upper section of the north pier, and which has for its function to prevent a motion in declination when the telescope is being moved in right ascension.

Slow Motions in Right Ascension and Declination.

Two methods of obtaining slow motion in right ascension have been provided. One is by means of a screw working in an adjustable block which displaces the arm of the right ascension clamp in the usual manner. It is operated by means of hand wheels at the eye end of the instrument.

The other is by differential gears placed between the clock train and the worm wheel. A small electric motor is geared directly to the largest of the wheels of the differential group, and by means of it they may be turned in either direction any desired amount. The motor is controlled by a switch at the eye end of the telescope. This form of slow motion has been found so satisfactory that it is used exclusively. It is especially convenient for guiding purposes with the spectrograph, since it is capable of giving large or small movements as may be desired, without producing appreciable vibration.

The declination slow motion is of the usual form, a screw working in an adjustable block at the end of the arm connected with the declination clamp.

Handles for the clamps and slow motions in right ascension and in declination are provided at both ends of the telescope tube.

Mirror Mounting.

The mirror mounting, taken in all its details, is rather complicated; more than three hundred parts enter into the construction of the cell and the mirror supporting system. The mirror rests upon six felt-covered bronze rings or cups, supported at the ends of three steel levers, which are pivoted at their centers upon blocks that are adjustable in height. Altogether these parts form a well distributed three-point support system for the mirror.

The mirror is held in place laterally by six leather-faced cast-iron blocks, which bear against it near its lower edge and thus prevent any large displacement. These blocks are all adjustable, but those on one side of the cell, when once ad-

justed, remain constant in position, while those upon the opposite side allow of some movement, being held against the mirror with moderate pressure by suitable spiral springs.

A carefully machined bronze ring, about three inches in width, encircles the mirror midway between its upper and lower edges, and is brought into practical contact with it by means of a felt band of such thickness as just to fill the space between. This ring is supported on the shorter arms of twelve levers, mounted to the inner side of the cell, with ball bearings, so that they are free to move about their fulcrums in any direction. The longer arms of these levers carry adjustable lead weights, so proportioned as to balance the weight of the mirror in any position.

Although the telescope is not intended to be brought into a position which will permit the mirror to move away from the bronze cups which support it at the back, provision is made to guard against such contingency by having adjustable holding down pieces, which are normally just in contact with the front surface of the mirror near its edge. These pieces are readily removable and are taken off when the mirror is being silvered.

Silvering the Mirror.

The large parabolic mirror may be resilvered without taking it from the tube and without disturbing its adjustments. Four large man-holes have been placed in the tube, a short distance above the mirror, to give easy access to it. Under ordinary conditions these are closed with wooden covers. When the mirror is to be resilvered the covers are removed, and so also are some of the slow motion rods, which happen to cross the holes, provision being made for readily removing them. The telescope is then placed with the tube in a vertical position, and the holding down clamps removed from the edge of the mirror. To prevent water and the silvering solutions from over-flowing, a band of parafined paper is bound tightly around the mirror, extending about six inches above the polished surface. A parafined wooden plug closes the central aperture. When these arrangements have been made the old silver coating may be dissolved, the surface washed, and a new silver coating deposited, with comparative facility, the successive solutions being removed by taking out the wooden plug and letting them flow through the central aperture into vessels placed below.

Program for Silvering the 37½-inch Mirror.

To ensure success in silvering the large mirror all details must be attended to very carefully. Dr. Curtiss has worked out the following program, which is printed here for convenience of reference.

1. Withdraw electrical plugs and place temperature case in position for removing spectrograph.

2. Let spectrograph down as far as possible by focussing apparatus.

3. By means of the fast motions in right ascension and declination, place spectrograph in position on the temperature case, using wooden shims if necessary and two wooden cross pieces.

4. *Put lead weights on lower end of telescope tube.*

5. Remove nuts and move focussing screws up as far as possible.

6. Push temperature case with spectrograph supported upon it out of the way, at the same time raising telescope to clear the spectrograph ring.

7. Take off the slow motion shafts.

8. Take off the holding down pads on the mirror surface.

9. Place paper dam around the edge of the mirror.

10. Remove old silver with nitric acid.

11. Clean mirror surface carefully with distilled water, leaving one-half of an inch of water (at edges) on the mirror.

12. Add silvering solutions, made up as follows:

Solutions.—To a solution of 200 gms. of $AgNO_3$ in 10,000 ccs. of distilled water add ammonia until the precipitate redissolves. Then add a solution of 100 gms. of KOH in 5,000 ccs. of water. Add ammonia until the second precipitate is nearly dissolved. When ready to silver add 1140 ccs. of the following solution:

Rock candy	90 gms.
Concentrated nitric acid (sp. gr. 1.22)	4 ccs.
Alcohol	175 ccs.
Distilled water	1000 ccs.

This is a stock solution which improves with age.

13. When the surface begins to look milky, drain off the solutions and flush the mirror surface with distilled water. Clean thoroughly.

14. Remove the paper dam while the mirror is still wet and flush the mirror again.

15. Remove water remaining on brass ring.

16. Replace holding down pads on mirror.

17. After the mirror is thoroughly dry, brush and burnish the surface.

18. Replace spectrograph and then remove lead weights.

19. Replace shafts, etc.

Mirror Cover.

The cover to the mirror is placed in the central section of the tube, a little below the declination axis, at a distance of about two feet above the surface of the mirror. This part of the tube is flat on one side, and it was possible to insert there a strong cover, made in one piece, which can be opened and closed at a single operation, like a door. A catch holds the cover in place when it is down. The cover is operated by means of a flexible cord from the eye end of the instrument.

This cover forms a part of the temperature case, described elsewhere. It is constructed of two layers of wood, having a space between, filled with a non-conducting material. The cover closes upon a circular felt ring.

Support for Secondary Mirrors.

The mountings for the hyperbolic and plane secondary mirrors were designed by Dr. Curtiss, with a view to rigidity and minimum light obstruction, together with ease of removal for silvering and ready focal adjustment along the optical axis of the telescope. The removal and replacement of either mirror without disturbance of the collimation adjustment has also been ensured in the design.

A bronze spool, coaxial with the Cassegrain optical system is supported rigidly in place by the usual system of four webs, stretched tightly across the telescope tube. The cylindrical hole, 3⅜ inches in diameter and six inches long, in the spool, is bored to receive a cylindrical casting which divides at the lower end into three spreading struts or legs to the feet of which the back plate of the mirror cell is attached by concentric collimating screws. The back plate of the mirror cell is a bronze annular disk, 11⅜ inches outside diameter, with three bosses on its back face to receive the collimating screws, and with its front surface accurately planed about the edge to receive the cylindrical part of the cell, into which the mirror fits. This cylindrical cell is constructed with a narrow inner flange on its front side, against which rests the edge of the front surface of the mirror, which is held in place by six adjustable steel springs, compressed by screws passing through the back plate of the cell.

The cylindrical tube carrying the mirror cell slides to and from the large mirror through a distance of two and one quarter inches, in the fixed bronze spool, a motion effected by means of a rack and pinion. One end of the pinion shaft carries a wooden handle that may be manipulated at the small mirror; the other end of the pinion shaft extends through the telescope tube to a pair of bevel gears by means of which the focal adjustment of the secondaries may be readily controlled at either end of the telescope tube, by slow motion handles. A given movement of the hyperbolic secondary to or from the large mirror causes a ten-fold change in the position of the focal plane of the Cassegrain combination. Thus the observer may easily alter the position of the focal plane in the Cassegrain form about twenty-three inches. This is much more than is required for seasonal changes and fully enough to make possible the use of extra-focal photometric apparatus, without the removal of the spectroscope. At the same time, with a little experience, this hand motion of the hyperbolic secondary enables an observer to maintain an accurate focal adjustment of the star image for spectrographic work with the minimum of inconvenience.

When a secondary is to be resilvered, the cylindrical tube and cell together are slid out of the fixed spool. The back plate is then unscrewed from the cell, and the cylindrical section of the cell containing the mirror is placed on some flat surface, on which the back surface of the mirror

rests. This part of the cell is then lifted off from the mirror. After silvering, it is obvious that the mirror can be restored exactly to its former position, with no danger of error, since every screw is simply driven home again and the collimating screws are not disturbed nor changed.

TEMPERATURE CASE.

The early experience with this instrument showed that the rapidly falling temperature during the early evening hours produced optical distortions in the mirror surface, and it was not until a condition of eqilibrium had been reached that the best results could be obtained. Accordingly, to decrease the daily range of temperature of the mirror and spectroscope parts, a temperature case was constructed, within which the lower part of the telescope tube and spectroscope are kept during the day.

The temperature case consists of a wooden frame, carrying a double covering of building paper overlaid with painted canvas, separated four inches, and with the intervening space filled with a non-conducting material. The case is mounted on casters, and may easily be moved from one position to another on the observing floor. It has doors on one side of sufficient size for the entrance of the spectroscope and lower part of the telescope tube. At the end of the night's work the tube is placed in a vertical position, the case is moved up to it, and the doors closed. The lower portion of the telescope tube and spectroscope are then fully enclosed within the case. Here they remain during the day. At night the case is removed when the temperature outside has fallen to that within it, as shown by thermometers, one mounted inside and the othe outside of the case, the one within being visible through a small window.

Under average conditions, the efficiency of this case is just sufficient to have the temperature within it equal to that without, an hour or two after sunset, and this may be regarded as the most desirable working condition, since it enables the observer to begin his work soon after dark.

The temperature case is provided with supports for carrying the spectroscope when it is not attached to the telescope.

FOCUSSING FOR SPECTROSCOPIC WORK.

The spectroscope is supported by a frame, which may be moved in or out by means of a system of connected screws, operated by two handles similar to the slow motion handles in right ascension and declination. This system is also operated by a ratchet, the handle of which is within easy reach of the observer when looking through the guiding telescope of the spectroscope. By means of the ratchet a very accurate focal adjustment of the spectroscope may be made.

The focal adjustment may also be obtained by altering the distance between the hyperbolic and parabolic mirrors. The hyperbolic mirror is supported in such a way that it may be moved along the axis of the telescope by a rack and pinion, without deranging the collimation. This movement is controlled from the eye-end of the telescope by means of shafts and gears operated by a hand-wheel similar to those employed for the slow motions in right ascension and declination. When care is exercised, this method will give an accurate adjustment of the focus upon the slit, and in practice it is this method that is generally used.

ELECTRIC CONTROL AT THE EYE END.

Every effort has been made to put the instrument under the complete control of a single observer. To this end most of the electrical connections have been carried to the eye end. When an observer is working with the spectroscope, he has circuits under his control, so that he may use them without leaving his position at the guiding telescope, for the following purposes:

1. For turning the dome in either direction, any amount.
2. For giving the telescope a slow motion in right ascension, in either direction, by means of the motor connected with the differential gears in the clock train. This form of slow motion in right ascension has proven so satisfactory that it is used exclusively.
3. For inserting the spark for the comparison spectrum, and for reversing it at pleasure from one side of the slit to the other.
4. For illuminating the hour angle scale and the declination circle.

5. For reading hand lamp.
6. For controlling the small fan motor in the spectroscope box.

The heating and thermostat circuits are also brought to the eye end of the telescope, but they are controlled from the switch-board.

Circuits are also installed on the instrument for illuminating the wires of the double slide plate holder, but these have not yet been used, since all the work of the instrument to the present has been in spectroscopy.

Pier.

The foundation of the pier is a block of reinforced concrete, twenty-eight feet long, twelve feet wide, and nine feet deep, made of broken limestone, gravel, sand, and cement.

A hollow, rectangular, brick pier is built upon this foundation, laid in mortar so rich in cement as to make it practically a cement structure throughout. It is twenty-seven feet long, ten feet seven inches wide, and rises to a height of twenty-eight feet three inches above the foundation. At this elevation the greater portion of the pier is arched over and finished with a level upper surface, on the south end of which stand the large castings, one upon another, which support the south end of the polar axis. The lowest of these castings is approximately rectangular, six feet by five feet at the base, and forms the room for the driving clock. This room has large iron doors on the east and west sides, making the clock easily accessible.

At the north end the brickwork rises seventeen and a half feet higher, in the form of a hollow, tapering, rectangular column, on the top of which are placed the castings which support the north end of the polar axis. The center of motion of the instrument is forty-five feet above the ground.

The brick walls of the pier are thirty-four inches in thickness, and they are connected by two cross walls, one seventeen and the other twenty-five inches in thickness. These walls and the floors divide the space within the pier into a number of compartments, which are accessible by a door in the basement and one on the main floor. The south compartment extends from the top of the pier to the level of the Basement floor, and forms the well for the driving clock weight.

Dome.

The dome for the reflecting telescope is forty feet in diameter and has a slit eight and a half feet in width, which extends from the horizon of the instrument to a point two feet beyond the zenith. The base plate is made of heavy castings, carefully planed and fitted, and rigidly bolted together, to form a complete circle. The principal girders are ten-inch I-beams, bent to the curvature of the dome, and extend from the base plate on one side to the base plate on the other side. They are placed parallel and enclose the slit between them. The secondary girders are six-inch I-beams, bent in a similar manner. They extend from the top of the dome to the base plate, and are at right angles to the principal girders. The remainder of the frame is made up mainly of 4 x 2-inch T-iron, placed three feet apart at the bottom, and converging toward the top of the dome. The dome is covered with heavy copper plate, which is fastened directly to the steel frame. A double shutter closes the slit. It is opened and closed by an endless rope passing over a sheave, connected with the gears and cables which form the shutter operating mechanism. The two halves of the shutter open and close simultaneously, and move parallel to each other.

There are eighteen dome wheels, each sixteen inches in diameter. They are mounted on the top of the wall in frames which are adjustable in height and direction, the adjustment in direction being for the purpose of centering the axes of all the wheels upon a point in the vertical axis of the dome. The base of the dome has a planed under surface, three inches in width, which forms the track. The dome rests directly upon the wheels, and is held in place laterally by nine guide wheels which are mounted on the wall and bear against the planed inner edge of the base plate.

A circular rack, made in sections about three feet in length, is attached to the under side of the base plate near its inner edge, and engages a spur gear which forms a part of the dome operating mechanism. The journals of the

dome wheels run in roller bearings. The dome turns easily and may be readily operated by hand, but an electric motor is ordinarily used for moving it.

The dome was constructed and erected by the Russell Wheel and Foundry Company of Detroit. They did not, however, furnish the wheel work, the guide rolls, the mechanism for turning it and for opening and closing the shutters. These were made by the Observatory Instrument Makers.

Design and Construction.

All the detailed drawings required for shop use in the course of the construction of the large reflecting telescope were made under my supervision at the Observatory. The first design of the instrument, with many of its characteristic features as they exist today, was drawn by Mr. E. J. Madden. This design was carefully studied and the numerous modifications which suggested themselves, were embodied in a later design, drawn by Mr. James H. Marks, who with his assistants worked out most of the details. He also prepared the drawings and specifications of those parts of the instrument which were made on contract. All the details of the spectroscopic and electrical equipment were planned by Dr. R. H. Curtiss, and the success of the instrument in these respects is due to him.

As soon as the design had been so far completed that the general features of the instrument were carefully determined, and the detailed drawing made of those parts which were first to be constructed, the actual work upon the mounting was begun. This was on May 1, 1907. The telescope was completed and ready for modern spectroscopic work four years later. In the year which has passed since its completion, it has been used for spectroscopic work, and more than seven hundred stellar spectrograms have already been secured.

From the beginning it was known that some parts of the instrument would be beyond the capacity of the machine tools of the University and Observatory Shops. These were made on contract. The Brown & Sharpe Manufacturing Company, Providence, Rhode Island, made the worm wheel and clamp ring in right ascension; The Charles F. Elmes Engineering Works, Chicago, Illinois, furnished the bare tube, the polar and declination axes, and two of the large castings for the south pier. The special ball and roller bearings were furnished by the Standard Roller Bearing Company of Philadelphia. All the other parts of the mounting were made by the Observatory Instrument Makers, Messrs. E. J. Madden, H. J. Colliau, E. J. Colliau, Thomas Madden, and Henry Larmee. The Messrs. Madden left the service of the Observatory in 1908, and the others have carried on the work of the last three years. They finished, erected, and adjusted the instrument, and installed its accessories.

COMET SEEKERS.

When the Observatory was founded, a four-inch comet seeker was obtained from Henry Fitz, of New York. It was a portable instrument, mounted on a tripod, and so arranged that it could be used either as an alt-azimuth or as an equatorial. It has been used extensively by students as an instrument of instruction, for the examination of familiar celestial objects.

In 1908, a new comet seeker was constructed in the Observatory Shop, by Mr. Henry J. Colliau. It is an altazimuth instrument, with "broken tube," and cylindrical stand, and is mounted on the roof of the Director's residence, in a situation easily accessible from the twelve-inch telescope. The optical parts of this instrument, an objective of four and one-half inches aperture and a three-inch totally reflecting prism, were furnished by the John A. Brashear Company of Allegheny. The horizontal axis forms a part of the tube, so that, for all zenith distances, the observer looks in a horizontal direction.

On the completion of the new comet seeker, the old one was dismounted, and its tube and objective taken as the finder for the large reflecting telescope.

CLOCKS AND CHRONOMETERS.

Tiede Clock, No. 125. This clock was obtained when the Observatory was founded, and notwithstanding more than fifty years of service, it is still in excellent condition. It was originally rated to sidereal time, and mounted on a pier

near the Meridian Circle, in a convenient position for making observations by the eye and ear method. It was here exposed to considerable variations of temperature, and on this account it was removed to a better situation, on the east face of the brick pier of the Twelve-Inch Telescope, and later still to the clock room in the new building. When it was removed from the meridian room, it was changed to a mean time rate, and has since been keeping Central Standard Time.

Howard Clock, No. 413. This is the usual pattern of Howard astronomical clock. It was obtained about 1893, and first set up in the room adjacent to that containing the Meridian Circle. In 1910 it was transferred to the clock room in the new building. It is rated to keep sidereal time. The pendulum is a steel rod, carrying a cluster of four steel jars, partially filled with mercury, for compensation. The second hand arbor carries a small wheel, whose teeth break the circuit and thus give the clock signals. The tooth corresponding to the 59th second is omitted.

Setting Clock. An inexpensive Seth Thomas clock, having a seconds' pendulum, and rated to sidereal time, is mounted on the wall of the meridian circle room. It is used solely for setting purposes.

Seismograph Clocks. Two inexpensive clocks are provided for giving signals on the seismograph sheets. They are mounted on the walls of the clock room. One is used at a time, and the other held in reserve. By operating through a relay, a single clock gives the signals for the hours and minutes, on the five seismographic records, simultaneously.

Chronometers. The Observatory has two sidereal chronometers, made by T. S. & J. D. Negus, of New York, bearing the numbers, 578 and 721; and one mean time break circuit chronometer, made by William Bond & Son, of Boston, bearing the number 588. The sidereal chronometers have been in the possession of the Observatory for many years. The mean time chronometer was received in 1910.

THE STUDENTS' OBSERVATORY.

In 1880, for purposes of instruction, there were added to the equipment of the Observatory a six-inch equatorial refractor, a three-inch transit instrument, with zenith telescope attachment, both made by Fauth & Company, of Washington, D. C., except that the optical parts were furnished by Alvan Clark & Sons, of Cambridgeport, Massachusetts.

These instruments were installed in what is commonly called the Students' Observatory, a small building of three rooms, an entrance, a transit room, and an equatorial room, situated about a hundred feet southeast of the main building. They remained in this location until 1908, when, to make room for the large reflecting telescope, which now occupies this site, the Students' Observatory was moved to a new location, about three hundred feet west of the principal building.

Six-Inch Equatorial. The six-inch equatorial has a substantial iron pier resting on a concrete foundation, steel tube, means of adjustment in altitude and azimuth, finder, slow motions in right ascension and declination, driving clock, and position filar micrometer with electrically illuminated threads. The value of one revolution of the micrometer screw, as derived by observations of transits of Polaris, is:

$$R = 42''.801.$$

A new driving clock, of the double conical pendulum type, and a new worm and wormwheel, were added to the six-inch telescope at the time of its removal. These improvements were designed by Dr. R. H. Curtiss, and constructed in the Observatory Shop by Mr. Henry J. Colliau. Slow motion in right ascension was provided by inserting differential gears between the clock train and the worm. These are operated by means of a small electric motor, controlled by a switch at the eye end of the instrument.

A camera has been attached to this telescope for photographing comets. It has a Bausch & Lomb-Zeiss Tessar lens, of 4.44 inches aperture and 19.5 inches focal length. When used for photographic purposes, the six-inch telescope becomes a finder, the guiding being done by means of the electrically illuminated threads of the micrometer. For very faint comets, the guiding is sometimes done on stars, in which case the micrometer wires are moved systematically

throughout the exposure to correspond to the rate of movement of the comet, the motion in declination being made by a proper setting of the micrometer in position angle.

Three-Inch Transit Instrument. This instrument is mounted in the meridian and has been used extensively for purposes of instruction. It is well suited to the training of students in the fundamental processes of meridian work, such as the determination of time, latitude, longitude, and instrumental constants.

The instrument has an iron base and standards, and rests on a concrete foundation. It has a clear aperture of three inches and a focal length of 46 inches. It is provided with reversing apparatus, setting circles on the axis reading to 10," zenith and striding levels, and a micrometer which may be rotated about the axis, through 90°, between adjustable stops. By reason of this rotation, the movable micrometer thread may be used either as a transit thread, or for the measurement of zenith distances. The sensitive zenith level is mounted on the setting circle, and has a clamp and tangent screw attached so that it may be set in any position. By reason of these arrangements, the instrument is suited to the determination of latitude by Talcott's method. From observations of 138 pairs of stars, by this method, made between October 6, 1886 and February 9, 1887, Dr. Ludovic Estes, determined the latitude of the Observatory, with the result

$$\phi = +\,42^\circ\ 16'\ 48''.66 \pm 0''.051,$$

referred to the latitude of the meridian circle.

The value of one revolution of the micrometer screw of this instrument is

$$R\ =\ 45''.031 = 3^s.002.$$

The value of one division of the striding level is $2.''750 = 0^s.183$, and that of the zenith level $0.''807$.

SEISMOLOGICAL EQUIPMENT.

Seismoscopes. During Professor Harrington's administration of the Observatory two small seismoscopes were obtained. One of them was mounted on the sub pier of the Meridian Circle and the other on the pier in the house intended for the transit of Mercury observations. These instruments were intended only to indicate the existence of seismic disturbances, without giving any other records of them than the times of their occurrence. Each of these instruments consists essentially of a vertical pendulum, hinged freely near its lower end, where it carries a small steady mass; and a light lever whose longer arm terminates in a point and is so bent that it can be adjusted to rest lightly upon the upper pointed end of the pendulum. By the action of the shock this adjustment was disturbed, and the lever, by altering its position, through mercury contacts, closed an electric circuit, which was arranged to stop a clock.

New Equipment. In August, 1909, a set of modern seismographs was installed in one of the basement rooms of the new building. The instruments include two Strassburg tromometers, of the Bosch-Omori pattern, a Wiechert astatic horizontal seismograph, of two components, and a Wiechert vertical seismograph.

These instruments rest upon a concrete pier, bedded in hard clay. It is impracticable here, on account of the region being covered with a thick layer of glacial drift, to carry the pier down to a rock foundation. The pier is isolated from the floor of the room and the walls of the building, by having a free space entirely around it, a few inches in width, extending down to a depth of about three feet.

All of these instruments have mechanical registration on smoked paper. A single clock, located in the clock room, working through a relay, furnishes the time record of hours and minutes on all the sheets simultaneously.

The Strassburg Tromometers. A modern seismograph consists essentially of a supporting pier, a pendulum which may be either vertical or horizontal and whose weight is called the "steady mass," and some means of recording the movement of the pendulum relative to the earth and the times of occurrence of such movements.

The so-called Strassburg tromometer is a seismograph, having a horizontal pendulum, made by Messrs. J. & A. Bosch, of Strassburg, Germany, according to the designs of the eminent Japanese seismologist, Dr. Omori. It has a steady mass of two hundred and twenty pounds, suspended in such a manner that it is free to

PLATE V. SEISMOGRAPH ROOM

move in a horizontal plane. A light trussed rod is fastened to the steady mass on the side opposite the supporting pier, and the outer end of this rod is pivoted lightly to the shorter arm of a magnifying lever whose longer arm carries the writing point. A cylinder carrying a sheet of smoked paper is kept in continuous movement by clock work, controlled by a governor of the double conical pendulum type. The friction of the writing point and of the pivot of the magnifying lever is not large, and when in adjustment the instrument is extremely sensitive and gives good records even of very distant disturbances. The instrument is provided with air damping mechanism.

In the installation of these instruments, the plane of suspension of one of them was made to coincide with the plane of the meridian, and that of the other with the prime vertical. They register, therefore, the east-west and north-south components, respectively, of earthquake disturbance.

Wiechert Horizontal Seismograph. This instrument has an inverted vertical pendulum, an air damping device, and recording mechanism. The pendulum has a steady mass of two hundred and twenty pounds, which is carried at its upper end, about forty inches above its support. It is supported at its lower end by two pairs of flexible steel bands, set at right angles to each other, in such a way that the pendulum, when disturbed, is free to move a limited amount about any horizontal axis passing through this support. Two thrust arms are connected with the steady mass, at right angles to each other, one in the north-south and the other in the east-west direction. These arms are connected with aluminum levers, which in turn are pivoted to the air damping devices and to the magnifying and writing mechanism. The levers are so arranged that both components of disturbance are recorded side by side on the same sheet. The air damping device consists of a light piston working closely in a brass cylinder, and is regulated by partially opening or closing a tube which connects the two ends of the cylinder. The damping may be cut off entirely or varied to any extent up to complete aperiodicity.

The magnification of the instrument may be varied from 40 to 160 times, and the period of oscillation from four to twelve seconds. By the use of steel bands for the supports much friction has been avoided, and that of the writing points and pivots has been reduced to a very small amount. The record of the clock signals for minutes and for hours is made by the writing point itself; when contact is made it is drawn aside for the moment by the action of an electromagnet.

Wiechert Vertical Seismograph. This instrument has a stationary mass of about one hundred and seventy-five pounds, placed at one end of a horizontal beam, which is pivoted at the other end and is supported near its center by a strong spiral steel spring. This spring is suspended from one end of a lever whose fulcrum rests upon the top of a gridiron column, made of zinc and steel rods, in the same manner that pendulums for clocks are sometimes constructed. The strength of the spring varies with changes of temperature and compensation is necessary to prevent displacements of the writing point, corresponding to variations of temperature. The gridiron column is intended to furnish the required compensation. In order that the injurious effects of rapid changes of temperature may be diminished as far as possible, the spring is enclosed in a wooden box and the entire upper part of the instrument is further enclosed in a double wooden case, having an air space between its layers.

An arm attached to the horizontal lever which carries the steady mass is pivoted to a double aluminum lever which connects with the air damping device and with the recording mechanism. The damping device is similar to that of the Wiechert horizontal seismograph. The period of the instrument is about six seconds and the magnification may be varied from forty to one hundred and sixty times. The record is made on a horizontal cylinder carrying a sheet of smoked paper, and the writing point is also used to mark the minutes and hours.

The Weichert seismographs were made by Messrs. Spindler & Hoyer, of Göttingen, Germany.

The Rossi-Forel Scale of Earthquake Intensities. This scale is extensively used for indicat-

ing the intensities of earthquake shocks, and for convenience of reference, we quote it here in the form given in the *Bulletin of the Seismological Society of America.*

I. MICROSEISMIC SHOCK: recorded by a single seismograph or by seismographs of the same model, but not by several seismographs of different kinds; the shock felt by an experienced observer.

II. EXTREMELY FEEBLE SHOCKS: recorded by several seismographs of different kinds; felt by a number of persons at rest.

III. VERY FEEBLE SHOCK: felt by persons at rest; strong enough for the direction and duration to be appreciable.

IV. FEEBLE SHOCK: felt by persons in motion; disturbances of movable objects, doors, windows; creaking of ceilings.

V. SHOCK OF MODERATE INTENSITY: felt generally by everyone; disturbance of furniture, beds, etc., ringing of swinging bells.

VI. FAIRLY STRONG SHOCK: general awakening of those asleep, general ringing of house bells; oscillation of chandeliers; stopping of pendulum clocks; visible agitation of trees and shrubs; some startled persons leave their dwellings.

VII. STRONG SHOCK: overthrow of movable objects; fall of plaster; ringing of church bells; general panic, without damage to buildings.

VIII. VERY STRONG SHOCK: fall of chimneys, cracks in walls of buildings.

IX. EXTREMELY STRONG SHOCKS: partial or total destruction of buildings.

X. SHOCK OF EXTREME INTENSITY: great disaster, buildings ruined, disturbance of the strata, fissures in the ground, rock-falls from mountains.

THE OBSERVATORY SHOP.

A modern Observatory makes many demands upon the Instrument Maker. New instruments must be installed; old instruments must be cared for and kept in a reasonable state of efficiency; auxiliary apparatus must be fitted to existing instruments and adapted to new needs; new forms of apparatus must be created for special investigations, and, from time to time, modified to meet the requirements of research. So numerous and varied are these demands that an Instrument Shop has become a necessary adjunct to a modern observatory. This is particularly true when astrophysical work is being done, where many experiments must be tried, and where special forms of apparatus are to be prepared under the immediate supervision of the experimenter.

On taking charge of this Observatory in October, 1905, I saw at once that extensive alterations would be required to put the instruments which it then possessed in a satisfactory condition for modern work; and that new and more powerful instruments, with much auxiliary apparatus, would have to be added, to enable the Observatory to undertake any investigations in the important department of astrophysics. Accordingly, upon my recommendation, by the action of the Board of Regents, in November, 1905, an Observatory Shop was established, for the repair and construction of instruments.

In the beginning, it was expected that the principal work of this shop would consist in making the lighter repairs to the instruments which the Observatory then had, and in constructing the auxiliary apparatus which would be needed in connection with them. It was accordingly fitted with excellent tools of moderate size, which have been in nearly constant use since their installation. But, after a time, it was found desirable to proceed to larger constructions than were originally contemplated, and to meet the increased demands, the shop space was enlarged and some additional machines obtained. At present the shop has two rooms, one 18 x 18 feet, and the other 18 x 46 feet, with the following equipment of power machine tools:

1 Pratt & Whitney Toolmakers' Lathe, 10-inch swing, 29 inches between centers, with full complement of chucks and tools.

1 Hendey Machine Company Lathe, 24-inch swing, 16 foot bed, 11 feet between centers, with full complement of chucks and tools.

1 Brown & Sharpe Universal Milling Machine, No. 1½, with slotting and vertical milling attachments, with arbors, cutters and tools.

1 Potter & Johnston Universal Shaper, 24-inch.

1 Cincinnati Milling Machine Company's Universal Tool Grinder, No. 1, with all attachments.

1 Barnes Drill Press, 20-inch.
1 Bench Drill Press.
1 General Shop Grinder.

In addition to the machine tools enumerated above, the Shop is supplied with a forge and a full complement of hand tools, such as are needed for accurate instrument work, and also with appliances for handling the large forgings and castings which are now being machined as parts of the twenty-four-inch Lamont refractor.

The Hendey lathe and the Potter & Johnston shaper were presented to the Observatory, in 1910, by Mr. R. P. Lamont of Chicago.

The Observatory has profited in its larger constructive operations by the courtesy of the Dean of the Engineering Department and the Superintendent of the Engineering Shops, who have placed their large tools at the disposal of the Observatory Instrument Makers, thereby enabling them to handle larger work than otherwise would have been possible.

The Observatory Shop has been taxed to its utmost capacity from the time of its foundation. Heavy duties have been laid upon it by the many repairs and smaller pieces of work which have been undertaken; by the very general reconstruction of the six-inch and twelve-inch refractors; by the design, construction, and erection of the thirty-seven and one-half inch reflector; by the completion of the stellar spectroscope, with its carrying frame and temperature case; by the installation of apparatus in the new building; and by the work now in progress; viz., the construction of two special engines for the measurement of celestial photographs, and the design and construction of the twenty-four-inch Lamont refracting telescope.

In the six years since its establishment, six Instrument Makers have been employed in the Observatory Shop, usually three or four at a time.

Mr. E. J. Madden was first appointed. He began work in January, 1906, and remained until June, 1908. In this interval, in addition to many miscellaneous duties, he organized the Observatory Shop, constructed the tube and driving clock for the twelve-inch telescope, made the preliminary drawings for the large reflecting telescope, and constructed the driving clock and portions of the north and south piers for this instrument. In the work upon this telescope, he was assisted by his brother, Mr. Thomas Madden, from May, 1907, to April, 1908.

Mr. Henry J. Colliau came to the Observatory in January, 1907 and his brother, Mr. Emile Colliau, in August of the same year. They have since been constantly employed here and have taken a conspicuous part in the production and installation of the equipment of the Observatory. It is not possible to notice in detail the many pieces of work which they have carried to successful completion. It should be mentioned, however, that they have constructed many of the parts of the large reflecting telescope, and, aided by Mr. Henry Larmee, who has been working with them since March, 1909, they have completed this large instrument, erected it in its dome, and put it in complete working order, without the necessity of calling in outside assistance.

During the past two years a large part of their time has been devoted to the miscellaneous accessories of this instrument and to the construction of the twenty-four-inch Lamont refractor.

Mr. E. P. Pegg was employed as an instrument maker at the Observatory for six months, in 1907, and with Mr. Henry J. Colliau, did much of the reconstruction of the twelve-inch refractor.

All the detailed drawings required for shop use have been made at the Observatory, under my supervision. The original design for the large reflecting telescope, exhibiting many of the features of the instrument as it exists today, was redrawn by Mr. James H. Marks, who with his assistants completed it in nearly all its details and embodied numerous modifications which, after careful study, it seemed desirable to make. He also prepared the drawings and specifications for the contract work on the instrument, and did much of the supervision of the work in the shop. All the details of the spectroscopic and electrical equipments have been planned by Dr. Curtiss and the success of the instrument in these respects is due to him.

The twenty-four inch Lamont refractor has been designed and developed in all its details by Mr. S. P. Langley, who has also had the supervision of its construction in the Shop.

LIBRARY.

The West Wing of the main building contains the Observatory Library. It has about twenty-seven hundred bound volumes and several hundred unbound books and pamphlets. It is composed almost entirely of technical works on Astronomy. It has nearly complete sets of the more important astronomical periodicals, the publications of the leading observatories and astronomical societies, and the principal treatises on theoretical and practical astronomy and astrophysics. The collection of star catalogues is large.

This is a department library, and does not attempt to duplicate the works found in libraries of other departments, or those contained in the General Library of the University. It does not, therefore, contain many books on pure mathematics, physics, chemistry, meteorology, etc., nor the proceedings of learned societies of a general character. Such works are naturally to be found in the General Library or in other department libraries, and when they are contained in such collections they are readily available for reference.

METEOROLOGICAL OBSERVATIONS.

Regular meteorological observations were begun at the Observatory in 1881 and have been continued without interruption since that date. From 1881 to 1904 inclusive the observations were made at 7:00 a. m., 2:00 p. m., and 9:00 p. m., as was done at all stations which were furnishing data during that period for the Michigan State Board of Health. This Board discontinued the collection of meteorological information in 1905, and since then the observations here have been made at 7:00 a. m. and 7:00 p. m., the hours adopted for making the observations by the United States Weather Bureau.

At present the observations made include the following: Atmospheric pressure, as determined by the standard mercurial barometer; air temperature, from properly exposed mercurial thermometers; direction and velocity of wind, from wind vane and anemometer; precipitation and cloudiness. Continuous instrumental records are also obtained of the velocity of the wind, as recorded by the anemometer; of the air temperature by a Richard thermograph; of the relative humidity by a Richard hygrograph and of the atmospheric pressure by a Richard aneroid barograph.

Public Service. From 1881 to 1904 inclusive, the meteorological results obtained at this observatory were communicated at the end of each month to the Michigan State Board of Health, for use in their investigations. In 1905 this Board ceased to collect information relative to the meteorological conditions within the state, the work being fully covered by the United States Weather Bureau.

The observations of this observatory have been regularly furnished the United States Weather Bureau, at the end of each month, and are now sent to the central station at Grand Rapids.

From April 1 to Septemer 30 of each year, the morning observations are telegraphed at 7:00 a. m., to the United States Weather Bureau Station at Chicago, for the use of the Corn and Wheat Section of that Bureau. Observations are also sent each morning by post card to the Ann Arbor Times-News, for publication in its columns.

May, 1900.

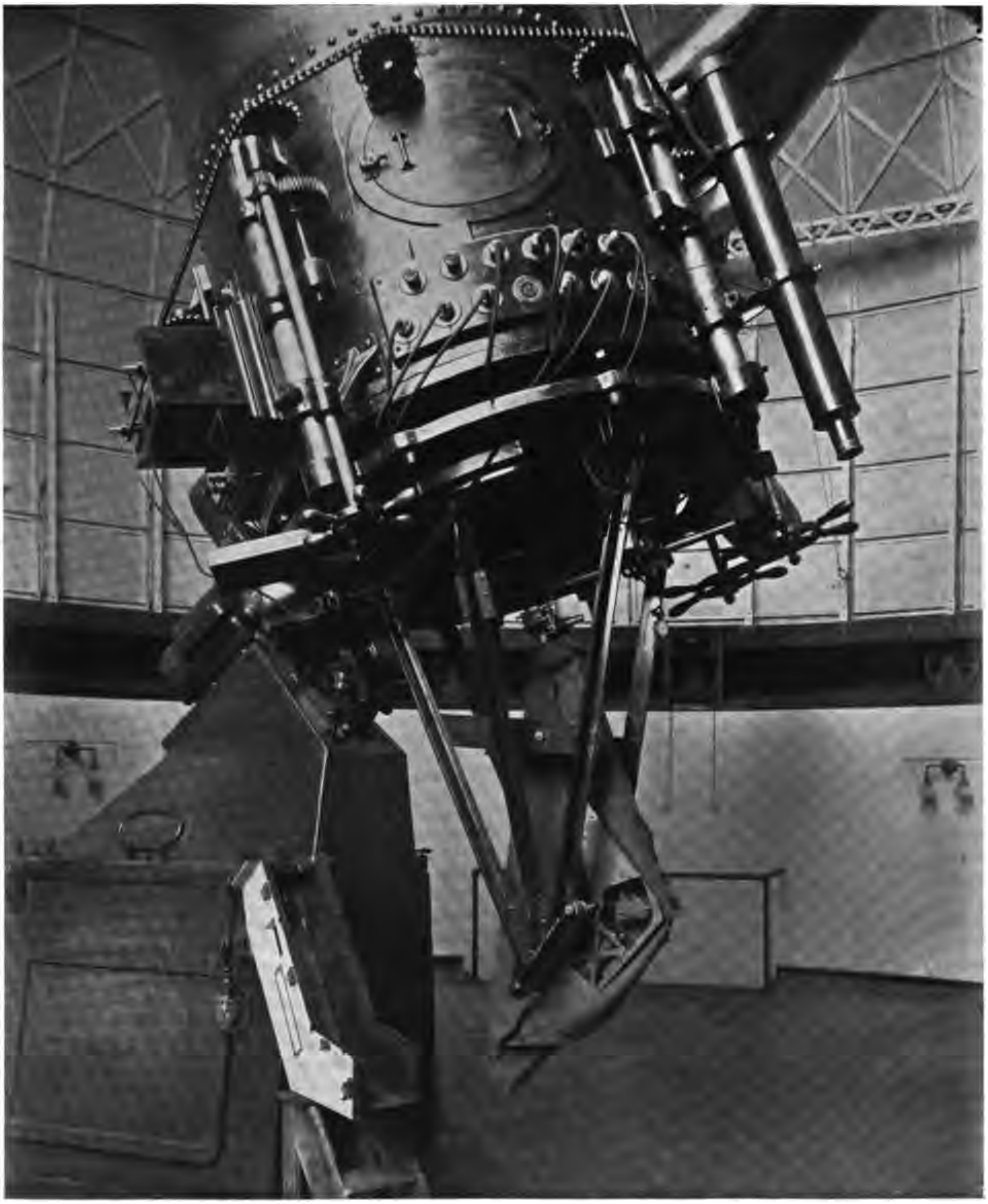

PLATE VI. SINGLE-PRISM SPECTROGRAPH

THE SINGLE-PRISM SPECTROGRAPH OF THE DETROIT OBSERVATORY.

By RALPH H. CURTISS.

The successful application of the single-prism spectrograph of the Lick Observatory to the study of the spectra of relatively faint Cepheid variables led the writer, in 1905, to recommend a program of low dispersion radial velocity work in connection with the Keeler Memorial Reflector of the Allegheny Observatory. The spectra of so-called early type, containing broad diffuse lines, seemed particularly adapted to study with a spectrograph of low dispersion. This class of stars alone, comprising as it does the short period Algol stars available for such studies as well as numerous other exceptional objects of great interest, promised a rich field for investigation. A year and a half later, though this domain of astrophysics had been entered by several new investigators, the problems involved seemed even more pressing and no hesitation was felt in deciding upon a program of low dispersion quantitative and qualitative spectrographic work in connection with the then projected reflecting telescope of the Observatory of the University of Michigan.

In March, 1907, Professor Hussey placed the order for the new spectrograph with the John A. Brashear Company of Pittsburgh, Pennsylvania. This order specified an instrument of the same general type as that of the Mellon Spectrograph of the Allegheny Observatory, with such changes as the writer might specify. These changes were embodied in an entirely new set of drawings of which those for the brass box or spectrograph proper were submitted to the John A. Brashear Company and were adapted to shop use. That the work of this firm was excellently done need not be said. The spectrograph box complete with optical parts, slit-head, comparison apparatus, plate holders, thermostat and thermometers, was delivered in Ann Arbor, in January, 1909.

Investigations of the optical parts and mechanical construction were immediately undertaken and the results were embodied in papers read before the Astronomical and Astrophysical Society of America in the following August. These results also appear in this volume. With the successful termination of these investigations it became possible to complete the design for the supporting truss, constant temperature case, and guiding microscope, and by special arrangement with the John A. Brashear Company these were constructed from our designs in the Instrument Shop of this Observatory.

With the completion of the large reflecting telescope the spectrograph went into use, the first spectrogram being made early in 1911. A regular program was begun in the following May, yielding exposures on stellar spectra numbering six hundred and fifty to the first of June, 1912, sufficient to give assurance of the success of the instrument.

DESIGN.

The stellar spectrographs of the present time may be considered in two general classes according to the type of mechanical construction employed. In the first type the supporting system and the spectrograph proper form a single unit in the form of a cantilever beam. This type of spectrograph seems relatively more liable to flexure displacement of spectral lines at the camera focus and is not as adaptable as possible to temperature control. In the second type of stellar spectrograph the optical parts, slit head and plate holder are combined in one distinct unit, forming the spectrograph proper; this to be carried, with every essential provision for relative motion, by an independent truss or supporting cradle, in position at the focus of the telescope. In this type of instrument flexure effects are readily controlled and the construction and support of the temperature case is facilitated. This second type of spectrograph originated at the Lick Observatory and, as developed by Wright, is represented well in the Southern Mills' Spectrograph, used in Chile by its designer

and described in Volume IX of the *Publications of the Lick Observatory*. A second instrument built upon this principle, but embodying new ideas of Campbell and Wright, was completed at the Lick Observatory in 1902, and immediately supplanted the original Mills spectrograph, as the chief observing instrument for the extensive radial velocity programs of the Lick Observatory. It was this instrument which served as a prototype for the single-prism spectrographs which have recently been constructed at Allegheny, Ottawa, and Ann Arbor.

The Mellon Spectrograph of the Allegheny Observatory was the first permanent single-prism instrument of this type. In it were embodied the writer's ideas, as gained during several years' work at the Lick Observatory and as developed under the supervision of Professor F. Schlesinger. But aside from the modifications necessary to adapt the construction of the New Mills Spectrograph to the requirements of the single-prism type, no important new features were introduced in the design.

The success of the Mellon Spectrograph in its particular field needs no further demonstration. To the writer no far reaching measure toward improvement in its mechanical construction seems obvious. But upon considering possible modifications for a larger and heavier instrument for this Observatory, several changes, partly experimental, seemed worthy of adoption largely on the basis of experience with the Allegheny instrument.

SINGLE-PRISM SPECTROGRAPH OF THIS OBSERVATORY.

In the design of the moving spectrograph intended for quantitative work on stellar spectra at the University of Michigan, the chief desiderata in view aside from "identity of source," were excellence of definition over a large region of the spectrum, light efficiency, invariability of position of photographic images on the plate during exposures, and convenience of manipulation. It was intended to sacrifice dispersion and resolving power only so far as necessary to the furtherance of the above ends, keeping in view the requirements prescribed by the nature of the investigations intended.

THE OPTICAL PARTS.

In selecting optical parts with the above considerations in view there was no hesitancy in adopting the Hastings-Brashear Single Material Camera Doublet, as tested successfully at Ottawa.

The prism of O:102 glass was selected at once, but the Isokumat Collimator Lens was taken on trial, because of the well-known strong light absorption of one of the elements of this lens.

THE COLLIMATOR LENS.

The dimensions and focal lengths of the optical parts represent a compromise between considerations of dispersion and resolving power on the one hand, and of light efficiency and compactness on the other. The Isokumat Collimator Lens has an aperture of 36.6 mm. (1.43 inches) and a focal length for $H\beta$ light of 686 mm. (27 inches).

THE PRISM.

The prism is constructed of O:102 glass, bearing the number 0.3732. The makers' indices of refraction are as follows: 1.6413 for $H\alpha$ ($\lambda = 6563.1$ Å), 1.6467 for D ($\lambda = 5893.2$ Å), and 1.6603 for $H\beta$ ($\lambda = 4861.5$ Å). On the basis of these indices the constants of a Hartmann interpolation formula are found to be $n_0 = 1.6113$, $\lambda_0 = 2185$, and $c = 131.17$. And the value of the index of refraction for $\lambda = 4415$ Å is found to be 1.6701 and for $H\gamma$ ($\lambda = 4340.6$ Å), 1.6722. A deviation of 60° for $H\gamma$ light having been determined upon, the refracting angle of the prism was made 63° 36′, and to make full provision for the free path of the beam the height of the prism was made 43.2 mm. (1.70 inches) and the length of the refracting faces, 74.4 mm. (2.93 inches). The proportion of $H\gamma$ light transmitted by this prism, not considering losses by reflection, was found on theoretical grounds to be about eighty-one per cent. and maximum transmission was secured when the refracting edge was placed three fourths of a millimeter inside of the edge of the beam. In actual practice the refracting edge of the prism is placed about one and a quarter millimeters inside of the edge of the beam.

THE CAMERA LENS.

The camera objective is a Hastings-Brashear single material doublet figured on the basis of the Hartmann-Zeiss homogeneous doublet of 1900. The objective of sixteen and one-half inches (420 mm.) equivalent focal length, consists of two lenses of light crown glass, five inches apart, with apertures of 1.75 inches (44.4 mm.) and 2.75 inches (69.8 mm.), carried in a bronze cylinder of about three inches outside diameter. The distance from the front lens to the focus is about seventeen and one-half inches (444 mm.). The inclination of the focal plane to the axis of the lens is about eighteen degrees.

When used in connection with a single prism and an Isokumat collimator lens, Plaskett has found this lens to be remarkably free from spherical aberration over a wide range of its unusually flat focal surface. A more intensive study has been attempted here, in order that every possibility of this particular lens might be realized, and the methods and results, the latter on a readily interpretable scale, will be useful to those contemplating optical parts of this kind.

In testing this combination the collimator focus for Hβ light was first determined by Schuster's method. Hβ was placed at minimum deviation and the inclination of the plate holder was adjusted to follow closely the focal curve. For any given adjustment of the optical parts the actual focal curve with reference to the plane surface of the photographic plate was determined by making eight exposures of sky spectra side by side on the same focus plate. Between each of these exposures the camera lens was moved along its axis a distance of 0.2 mm by means of a screw threaded in a nut fixed rigidly to the lens cell. Each plate was examined under a microscope, and for a large number of groups of Fraunhofer lines, throughout the spectrum, estimates were made of the camera settings which would give the best definition. These estimates of camera settings, plotted against distances measured along the spectrum, furnish for any given focus plate the focal curve or curve of best focus with reference to the plate surface. This method avoids some objectionable features of extra focal observations and is capable of high accuracy.

The plates used in this investigation were Seed 23's, Seed Red Label Lantern Slides bathed in Pinachrome, and Cramer Spectrum Process Plates. The range of spectrum covered was from λ 3850 Å to λ 6000 Å.

In the manner described focal curves were determined for nine different cases, as shown in Plate VII, involving nine different combinations of collimator and prism settings. Three settings of the collimator, one-eighth of an inch outside and the same distance inside of the Hβ setting and the Hβ setting itself, were combined separately with three prism settings at minimum deviation for λ 3900, Hβ and λ 6500. In the figure the first, second and third rows of curves correspond to minimum deviations for the rays, λ 3900, Hβ and λ 6500 respectively. The first, second, and third columns correspond to collimator settings one-eighth of an inch inside of the Hβ setting, the Hβ setting, and one-eighth of an inch outside of the Hβ setting respectively. Thus, these nine cases cover all possible combinations that might be advantageous in practice. From them it is possible to determine the best adjustment of the optical parts for the greatest flatness of field.

As indicated in the illustration, the horizontal spaces correspond to 0.2 mm. measured parallel to the optical axis of the camera lens. Wave lengths are indicated in the upper middle curve.

It is obvious at once that the general inclination of the focal curves is strongly affected by change of the optical adjustment; but since the plate holder is adjustable to any inclination, this does not concern us at present. We are interested, however, in the deviation of the curve from a straight line, for this is the measure of the departure of the curve from flatness. This deviation of the curve from a straight line may be investigated over either a given range of spectrum or a given linear distance along the spectrum. And in the figure the full lines through each curve show the deviation of the focal curves from a straight line from λ 4000 to λ 5900. The dotted lines exhibit the same deviation over a range of thirty-four millimeters measured from λ 5900 toward the violet end of the spectrum.

It is evident at once that the deviations for the fixed distance of thirty-four millimeters vary but

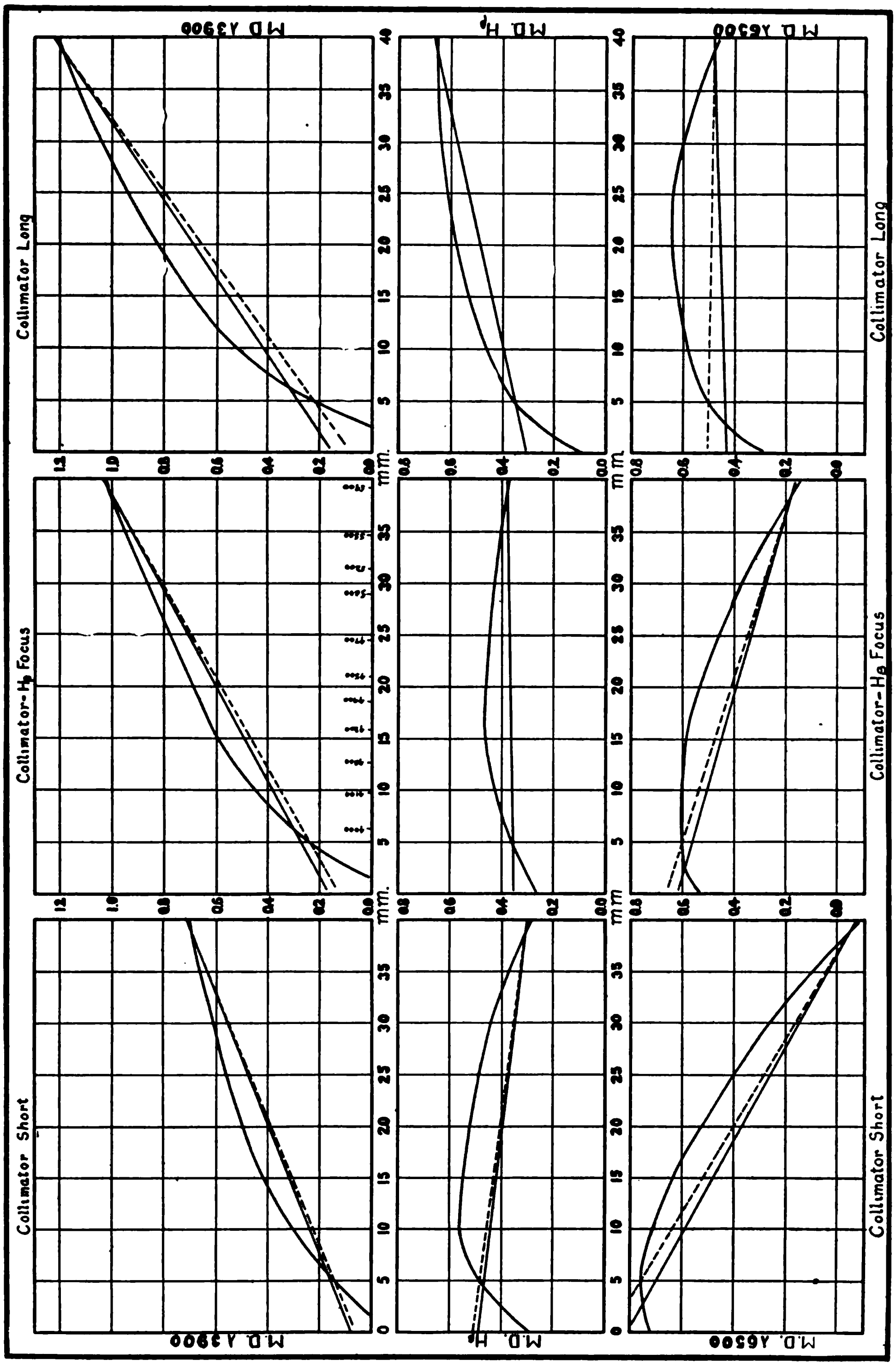

PLATE VII. FOCAL CURVES OF THE SINGLE-PRISM SPECTROGRAPH.

little for all nine cases. It is to be noticed, however, that the form of the curve on the end of shorter wave-lengths differs considerably in different combinations, seeming to diverge faster for longer collimators with minimum deviation settings for longer waves. But curve 2 is an exception, in which the curvature of the plate surface is probably involved. Again, the point of maximum deviation from the plate surface seems to shift slightly toward the red for minimum surface between λ 4000 and λ6000 is dependent upon the optical adjustments. For the longest collimator the flattest curve is secured with a minimum deviation at about λ 4700. For the Hβ collimator setting the flattest curve is obtained with λ 4400 at minimum deviation, and for the short collimator the best curve is obtained with λ 4100 at minimum deviation. But for each length of collimator the best curves seem to be about equally good, except possibly for the de-

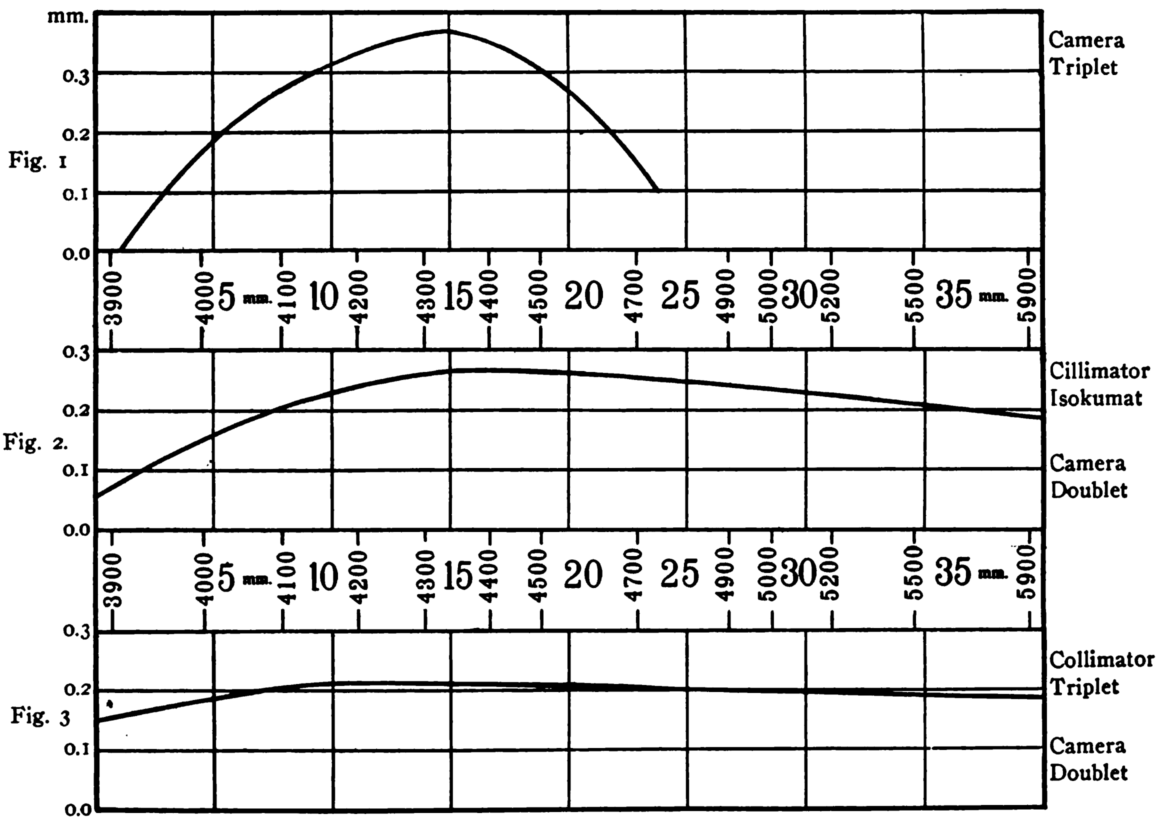

PLATE VIII. FOCAL CURVES.

deviation settings for greater wave-lengths. And for any collimator setting, the Hβ minimum deviation gives a curve as flat as or flatter than the others for that collimator setting. But any one of the three collimator settings seems to give equally good curves in connection with Hβ minimum deviation.

In the more important case, a given range of wave lengths of least deviation from a straight line, is required. And it may be seen at once that the deviation of the focal curves from the plate viation in the ultra violet. Furthermore, for all these curves the definition at focus seems about equally good on all plates, being free from aberration as far as the spectrum is registered.

The focal curve for a collimator setting at the Hβ focus with the prism adjusted for minimum deviation at Hβ is shown in detail in Fig. 2, Plate VIII. The upper curve, on the same scale, is that of a Hasting's triplet in combination with a collimator doublet, all corrected for Hγ light.

In actual practice I have used a collimator

length one sixty-fourth of an inch shorter than the focal distance for Hβ light, have set the prism at minimum deviation for light of wave length, λ 4500 Å, and have inclined the plate surface to cover a range of spectrum in sharp focus from λ 3900 to λ 6000.

NEW COLLIMATOR LENS.

As soon as spectrograms of B and A type stars could be made with these optical parts it was noted that the K region in these spectra required for its clear portrayal about twice the exposure used for the region about λ 4500. This unequal absorption could be attributed in part to the collimator isokumat, and since the use of the Hastings triplet as a collimator lens in combination with the single material doublet promised improved absorption conditions and possibly a flatter focal curve, a new Hastings triplet was immediately ordered and was substituted for the collimator Isokumat in May of this year.

The new collimator lens has essentially the same dimensions as the old one and is corrected for the same spectral region. In both directions in which improvement was hoped for the results have been satisfactory. In the region of the spectrum above λ 4500 the new lens is noticeably more transparent. At the K line the new combination transmits about fifty per cent more light than the old one. The improved flatness of the focal curve with the new combination is particularly striking. Indeed the variation of the focal curve from perfect flatness under these circumstances is so slight that measurement of this deviation becomes quite difficult. In Fig. 3, Plate VIII, the focal curve depending on three independent determinations is drawn in parallel with the curves noted above. As in the case of the combination of Isokumat and Single Material Doublet the minimum deviation is set for λ 4500 and the collimator is a little shorter than the focus for Hβ light. Whereas with the combination of Isokumat collimator lens and single material doublet the deviation of the focal curve between λ 3700 and λ 5900 from a plane plate surface is nowhere greater than 0.07 mm., with the *new* combination this deviation is nowhere greater than 0.025 mm. and from λ 4200 to λ 5900 no certain deviation of the focal curve from flatness can be observed even on the large scale here employed. At the same time the focus is sharp and no trace of aberration in the comparison lines is observable even at the edges of the plate over the region examined from λ 3700 to λ 6000.

It would seem that the use of these optical parts is a step in advance, since they not only increase the available field over that given by other combinations but they should eliminate the errors known to arise from wings, associated with comparison lines, caused by spherical aberration when inferior camera lenses are employed.

EFFICIENCY CONSTANTS OF THE OPTICAL SYSTEM.

The constants defining the efficiency of the optical system of this spectograph are contained in the accompanying table. The purity and difference in wave length just resolved are based on Schuster's old formula for a slit width of 0.025 mm.

EFFICIENCY CONSTANTS OF THE OPTICAL SYSTEM.

CONSTANTS WAVE-LENGTH	RESOLVING POWER	PURITY	dλ RESOLVED	LINEAR DISPERSION t.m. per mm.	EQUIVALENT OF 0.001 MM. DISPLACEMENT
4000 Å	27,000	6,100	0.66 Å	26.7 Å	2.00 KM.
4500 Å	16,000	5,700	0.79 Å	44.1 Å	2.94 KM.
5000 Å	11,000	2,900	1.73 Å	65.2 Å	3.91 KM.
6000 Å	5,400	1,600	3.7– Å	133 Å	6.6– KM.

MECHANICAL PARTS.

In the design of the mechanical parts of this spectrograph especial effort was made to secure two of the desirable features in the moving spectrograph as mentioned above; viz., invariability of position and sharp definition of the spectral features on the photographic plate during exposures. And in this connection errors arising from flexure and temperature change were kept more particularly in view.

The considerations arising from flexure variations which dictated the form and material employed are summarized here.

1. The portion of the spectrograph carrying the slit, optical parts and plateholder should be as rigid as limitations of weight may permit. Local flexure at important points should be carefully guarded against.

2. This portion of the spectrograph (spectrograph proper) should be so supported that its flexures in the plane of dispersion will be compensatory and leave the position of any spectral line on the plate undisturbed with changing position of the telescope.

3. Flexures of the supporting system of the spectrograph should not be communicated to the portion of the instrument carrying the optical parts, slit-head and plate holder.

4. This supporting truss should maintain the spectrograph in position behind the telescope without sensible variation (0.01 inch at the collimator lens) in position relative to the telescope.

The considerations affecting the form and material employed and arising from temperature changes in the apparatus are as follows:

1. The supporting system of the spectrograph should be free to expand or contract with changing temperature without placing the spectrograph box under stress.

2. The spectrograph proper should be attached to the telescope in such a way as to permit a minimum flow of heat from the box to the support or *vice-versa*.

3. The support should join the spectrograph as far from the optical parts as practicable.

4. The portion of the box carrying the optical parts, slit-head and plate holder should be made of homogeneous material, so that with temperature change its form will remain unchanged. No thermal couples should be permitted.

5. This homogeneous material of which the spectrograph proper is made should be a good conductor of heat, in order to distribute quickly any local changes of temperature.

6. If possible the material of which the spectrograph proper is made should be such that its expansion and contraction with temperature change will counteract the changes in the focal distance of the lenses due to temperature variations.

7. A temperature case with efficient heat control should enclose the spectrograph proper as conveniently as possible. This case should be large enough to permit free circulation of air within and should be provided with some means to prevent stratification of air of different temperatures about the instrument.

Nearly all of the above considerations point toward an instrument of the type invented by Wright and adapted to single prism construction at the Allegheny Observatory. Considerations 2 and 3 under flexure can not be secured with the single prism spectrograph of cantilever type, and the isolation of temperature effects in the spectrograph proper as well as the insulation of this essential part of the instrument against temperature change are problems greatly simplified in the spectrograph of the simple beam type.

A brief description of the mechanical parts of the single-prism spectrograph of this Observatory is perhaps essential in order to define the character of the new features introduced. In connection with the illustrations of Plates VI and IX but few words are necessary to convey an adequate idea.

THE SPECTROGRAPH BOX.

For the purpose of description this instrument may be considered as made up of two parts, the spectrograph box and the supporting system, which are mechanically separable and which perform very different functions in the construction. The former carries the slit-head, optical parts and photographic plate in their proper relative positions; the latter supports the spectrograph box in its proper position with reference to the telescope.

The spectrograph box is a triangular skeleton beam, three and one-fourth inches wide, with sides, twenty-three, twenty-eight, and forty inches in length, and one-quarter inches thick. The internal members of the beam vary in thickness from three-sixteenths of an inch to one-fourth of an inch and in length according to their position in the construction. The slit-head is placed at the more acute angle of the triangle, the prism with collimator and camera lenses at the obtuse angle, and the plate holder at the remaining vertex, the plane of dispersion containing the axes of the lenses being half way between the two triangular faces of the beam. The two supports or points of attachment are placed approximately in the bisectors of the acute angles of the triangle, each about the same distance (eleven inches) from the nearest vertex. The internal members of the truss are then distributed so as to secure great rigidity, especially about the optical parts and points of attachment, and are so designed as to support the lenses, slit-head and plate receptacle and to make provision against all stresses that may arise in any working position of telescope. In Plate IX where the distribution of the members of the beam is shown it will be seen

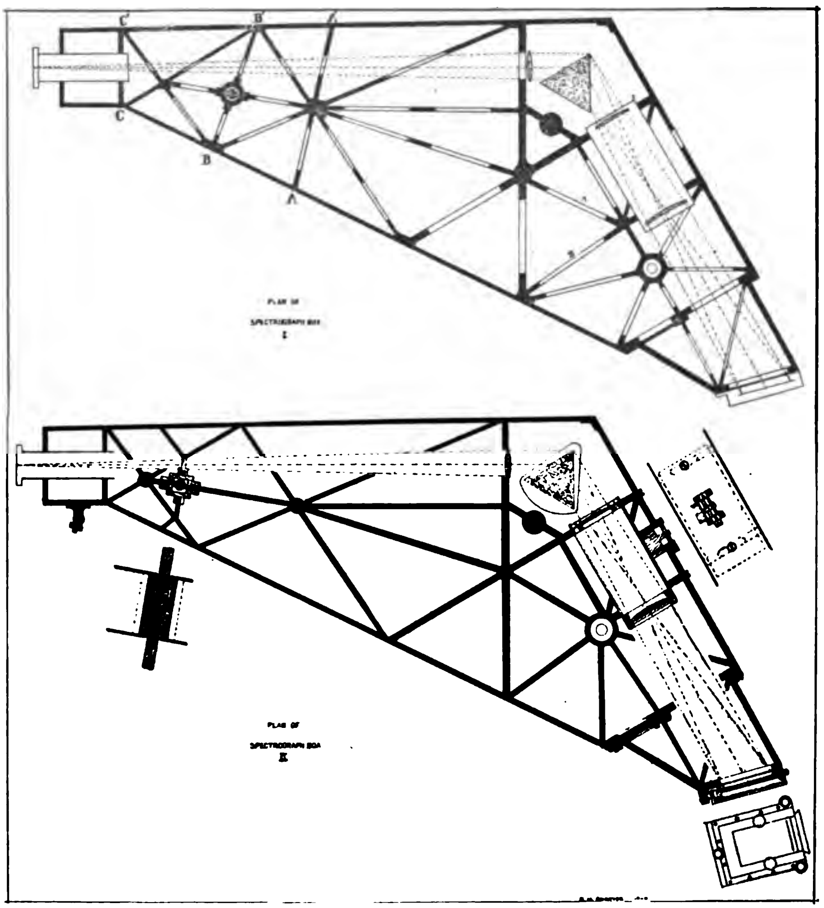

PLATE IX. PLANS OF SPECTROGRAPH BOX.

that the element of strength is carried to its logical limit and that the spectrograph box as constructed ought to satisfy all demands of internal rigidity. However, further resistance to stress is incidentally obtained by two plates, one-sixteenth inches in thickness, which cover the triangular or open faces of the box and which are fastened by numerous screws to the outer and internal members of the beam.

It will be noted that the spectrograph box is

not a unit, however. A section near the plate holder is made removable to make possible the use of a camera lens of twelve inches focus, but the reinforcement of the box at the junction of the added section with the box proper undoubtedly overcomes any weakening of the construction at this point.

The materials of which this box is constructed are brass and bronze exclusively. It was originally stipulated that the spectrograph should be made entirely of brass, in order that expansion and contraction with a given temperature change might be equal in every part, and also in order that heat conduction to equalize any local changes of temperature might be very rapid. Also it was expected that the use of brass in connection with the optical parts would compensate for changes of the focal plane with temperature change, an expectation which has been fully realized. However, on a suggestion of the J. A. Brashear Company that the use of certain bronze castings would facilitate their work, it was decided to depart thus slightly from our original plan, since the constants of bronze are so closely similar to those of brass. Accordingly that section of the internal frame work of the skeleton beam inclusive of the member which supports the collimator lens and extending to the removable section near the plate holder was made of cast bronze and was fitted with duplicated peripheral members into the construction. In this bronze casting all the optical parts including the prism are mounted and the main support of the spectrograph is attached. Another small bronze casting at the slit-head supports the slit-head tube, and a third bronze casting was introduced in our shops to secure great rigidity about the second or upper support of the box.

In the spectrograph box, the plate holder, optical parts and slit-head are mounted without the use of the conventional collimator and camera tubes. The collimator lens, with appropriate opposing screws for adjustment of the axis of the lens, is mounted directly on an internal member of the box, the member forming one of the sides of the prism box. The prism mounting, adapted from that of Keeler, is supported upon a face of the prism box perpendicular to the refracting edge of the prism and forming a part of the extensive bronze casting above described. The camera lenses in their cylindrical cell, five inches in length, and three inches in diameter, are also supported by two parallel members of this casting, in which motion of the lenses for focal adjustment is secured by a nut and screw of thirty threads to the inch, readily accessible on the exterior of the spectrograph box and permitting adjustment of the length of the camera with an accuracy of about one-onethousandth of an inch. A scale with an indicator registers full turns of the screw. The plate receptacle of conventional type but with heavy base plate is attached with opposing screws to the spectrograph box, on a face matching the base plate and making a suitable angle with the axis of the camera lens. The opposing screws permit the final adjustment of the plate surface to follow the focal plane of the single material doublet. The slit-head is carried upon a bronze tube supported by two parallel members of the spectrograph box, four inches apart. A shoe, half way between these supports, clamps the tube firmly in position. The length of the collimator and the orientation of the slit are varied by sliding and rotating this tube without the aid of rack and pinion or any other mechanical device.

FLEXURE AND DISTRIBUTION OF SUPPORTS.

(This section is taken from a paper read in August, 1909, at a meeting of the Astronomical and Astrophysical Society of America).

In the case of the single-prism spectrograph there is known to be considerable danger of error arising from internal flexure. Whatever displacement is present becomes of greater importance in the low dispersion spectrograph because of its greater value in equivalent velocity. It is therefore unfortunate that this form of instrument is especially liable to error of this kind.

The prevailing type of single-prism spectrograph which was evolved from the old visual spectroscope is essentially a cantilever beam with the slit near the plane of support, the plateholder farthest away where flexure deflection is a maximum and the optical system in an intermediate position. From the well known properties of a cantilever beam it is obvious that relative deflections of the plate and optical system of a one

prism instrument as referred to the slit may cause considerable displacement of spectral lines when the position of the spectrograph is changed. To be sure frequent introduction of the comparison will minify the error arising from differential flexure but since a star's image varies in intensity with zenith distance and also since flexure displacement is not a linear function of the hour angle, it can hardly be safe to assume that all appreciable error is eliminated in this way. And in view of the surprisingly large flexure displacements of 80 to 100 km. per second noted by some observers between two positions of spectrographs of the cantilever type, there seems to be a condition here that has needed attention.

The actual flexure displacements of lines from their mean positions in the direction of velocity shift on the spectrogram will in general follow a complex law difficult to predict. A valuable approximation may be obtained however, if we assume the simple sine formula and apply it to the case of the moving spectrograph attached to the eye end of an equatorial telescope, the plane of dispersion in accordance with common usage being coincident with the plane of the hour circle of the observed object. Flexure of the prism through faulty mounting is not considered here since such errors can be eliminated in any type of spectrograph. We assume then that the displacement of any line from its mean position is the product of the maximum flexure and the factors necessary to project the weight of each differential mass across a line which is vertical when the flexure is zero. Since the spectrograph is not in general a symmetrical beam with reference to any flexure axis or line of support the simple sine law will not express the flexure rigidly, though such an elementary representation of flexure and displacement is of interest and value.

Adopting as the normal position for any spectral line the mean of all positions it may occupy when the spectrograph is rotated through 360° in the meridian we may define :

F, The flexure displacement of any spectral element from its mean position in the direction of velocity shift. Positive displacement toward the red.

F_m, The maximum value of "F" on the meridian when the telescope is east pointing north of the zenith.

Axis of flexure, A line through the slit in the plane of dispersion of the spectrograph; vertical when $F =$ Zero and approximately horizontal when $F = F_m$.

α, The angle between the axis of flexure and the axis of the telescope or collimator; in other words, α is the zenith distance of the observed object when $F = O$ on the meridian. α is positive when the declination of the intersection of the axis of flexure with the celestial sphere is greater than that of the observed object.

A, The intersection of the axis of flexure with the celestial sphere.

Z, The zenith of distance of A.

Q, The parallactic angle of the telescope pointing.

t, The hour angle of the telescope pointing.

δ, The declination of the telescope pointing.

ϕ, The observers latitude.

For the simple case of a meridian object we may write

$$F = \pm F_m \sin Z = \pm F_m \sin\ (\delta - \phi + \alpha)$$

where the last upper and lower signs refer to telescope east and west respectively. In the general case of an object with coordinates, t and δ, the weight of each differential mass producing flexure must be projected into the plane of dispersion and perpendicular to the flexure axis. Two functions effect this. Sin Z defines the component of the weight normal to the axis of flexure in the vertical plane containing the axis of flexure. The factor, Cos Q, projects this component into the plane of dispersion. Thus we may write on the basis of the sine law,

$$F = \pm F_m \sin Z \cos Q,$$

which becomes, since

$$-\cos Q = \frac{\cos(\delta+\alpha)\sin\phi - \sin(\delta+\alpha)\cos\phi\cos t,}{\sin Z}$$

$$F = \pm F_m[-\sin\phi\cos\ (\delta+\alpha) + \cos\phi\sin(\delta+\alpha)\ \cos t].$$

This equation expresses the actual value of F in any position of the telescope when F_m and α are known. From it we may deduce the variation

in F or the flexure variation for any given star when t changes.

Let $F = F_1$ when $t = t_1$,

and $F = F_2$ when $t = t_2$.

Then

$F_2 - F_1 = \pm F_m \cos\phi \sin(\delta + a) [\cos t_2 - \cos t_1]$

where the upper and lower signs refer to telescope east and west respectively.

From this simple equation expressing the variation of flexure displacement in the direction of velocity shift with hour angle, some interesting deductions can be made as follows:

1. For any object the variation of flexure displacement is always smallest at or near the meridian.
2. Flexure displacement for any star is the same in magnitude and direction at hour angles symmetrical with respect to the meridian unless the telescope be reversed.
3. For any object and spectrograph, flexure variation is proportional to cos ϕ. Hence it is zero at the poles and a maximum at the equator. Higher latitudes are advantageous in this respect.
4. For any object for which $\delta = -a$ flexure variation with hour angle is always zero. When $\delta = \pm \pi/2 - a$ flexure variation with changing hour angle becomes a maximum in any given latitude and the expression above becomes

   $F_2 - F_1 = \pm F_m \cos\phi\ [\cos t_2 - \cos t_1]$.

   Since a reverses its sign when the telescope is reversed over the pier there must be two declination circles distant a from the equator on which there is no flexure variation and two others distant a from the poles on which flexure variation is a maximum. For the single prism instrument for which a is about twenty-five degrees the regions of smallest differential flexures are at $\pm 25°$ declination and the regions of greatest differential flexure are at $\pm 60°$ to $\pm 70°$ declination.
5. If $\phi = -a$, flexure variation becomes zero for objects crossing the zenith. This condition is therefore advantageous.

The flexure constants, F_m and a, depend upon the weight, coefficient of elasticity and distribution of materials in the spectrograph box including the slit, optical parts and plateholder. In the case of the single prism instrument, neglecting flexure of the prism mounting, the axis of flexure will probably follow closely a straight line joining the slit and its image in the camera, but in general a few measures of flexure in the meridian will be necessary to determine a and F_m and to discover the law of variation of flexure with zenith distance in case the sine law assumed here is inapplicable.

The values of F_m, a and ϕ furnish criteria bearing upon the freedom from flexure of any given moving spectrograph. If the instrument be mounted with slit east and west and attached to an equatorial telescope, on the basis of the sine law the best flexure conditions obtain when F_m is small, and ϕ, large and when a is the negative of ϕ.

The greatest flexure variation is one hour's exposure will occur when $\delta = \mp \pi/2 - a$ at an hour angle of ± 6 hrs. In this case in latitudes of 40° the differential flexure will amount to one fifth of the maximum flexure on the meridian. Since for the single prism spectrograph this value of δ may be in the neighborhood of 65° such an exposure is quite possible. An exposure of three hours in the same part of the sky would lead to a differential flexure slightly greater than one-half of the maximum flexure in the meridian. These results are in accordance with measures by Küstner who found in his 3-prism spectrograph a flexure of 75 km. per sec. at Hγ on the meridian and a flexure displacement of 12 kms. per sec. in an exposure of one hour in his least favorable region of the sky. In the case of single prism spectrographs of the cantilever type with flexures of 50 to 100 kms per sec. in the meridian, an exposure of three hours may entail a flexure of 25 to 50 kms. per second for any given spectral element during the exposure.

With these and other considerations in mind, several single-prism instruments of the simple beam type have recently been constructed. In this simple beam type of instrument flexure can be practically eliminated or made compensatory by suitably placing the supporting points or by the introduction of counterbalancing levers. The latter method was actually tried by the writer in the summer of 1906 in order to demonstrate that the displacements in the Mellon spectograph,

which he was then investigating, were really flexure displacements and that they could be eliminated by a moderate counter force opposing gravity at the plateholder. Later a plan embodying this method of flexure elimination was drawn up in detail for the new Detroit Observatory spectrograph. It has also been developed independently by Mr. Plaskett. The idea was finally rejected here however, in favor of the method of suitable distribution of two supporting points. The two sketches of Plate IX show sections in the plane of dispersion of two forms of spectrograph box each being about 3⅜″ deep and otherwise of similar dimensions. In each case the support near the prism is considered fixed in position and is a ball and socket joint. The upper support is to be determined by trial so that flexure between and outside of the supports will be compensatory. In the sketches I have indicated my predicted positions for the upper support near the slit but when the instrument was ordered from the J. A. Brashear Company it was stipulated that the upper support should be omitted entirely from the construction. Plan I, in which the adopted support is nearer the plate holder, was selected because it gave promise of a better position for the upper support and also because it was desirable to keep this communication with the metal parts outside of the temperature case as far from the optical parts as possible.

In determining the flexure of this instrument three pairs of points (AA′, BB′ and CC′, Plate IX, Fig. 1) were adopted for the upper supports. For each pair of points three exposures of comparison spectra side by side were made always with the plane of dispersion vertical and the longest side of the triangle horizontal but in the first and third exposure with the prism below and in the second exposure, which was between the other two on the negative, with the prism above. Thus apparently the double flexure or twice the so-called maximum flexure was measured in each case. The results follow.

SUPPORT	DOUBLE FLEXURE	DOUBLE FLEXURE IN KM. PER SEC. AT $H\gamma$
AA′	— 2.24 microns	— 6.3 KM.
BB′	— 0.52 microns	— 1.4 KM.
CC′	+ 1.39 microns	+ 3.9 KM.

It is thus evident if the sine law holds and if the position of the axis of flexure has been properly chosen that the point of support for zero flexure should be about one fourth the distance from BB′ to CC′ on the basis of these measures. However for symmetry of construction and because it is planned to remove a section of the box at the plate holder to permit the use of a twelve-inch camera objective instead of the sixteen-inch, it was decided to adopt the position for the upper support as shown in the sketch. This position should give flexures nearly equal and opposite for the twelve-inch and sixteen-inch cameras.

For the sixteen-inch camera the flexure has been determined with the upper support in place. The maximum flexure determined as before proves to be — 0.45 microns, the equivalent of — 1.3 km. per sec. at $H\gamma$. In an exposure of three hours in the least favorable region of the sky the change of position of the $H\gamma$ line due to differential flexure of the spectrograph box should be not greater than 0.6 kms. per sec. or about 0.00023 mms. In one hour this displacement of $H\gamma$ should not exceed 0.3 kms. in the least favourable region of the sky. These results have been obtained without temperature control and are also affected by flexure of the prism mounting. It is nevertheless clear that differential flexure is vanishingly small in this instrument as it stands; and there is good reason to expect that the same condition will obtain when the 12″ camera is employed, though the requirements will be even more exacting.

THE CHARACTER OF THE SUPPORTS.

The lower support of the spectrograph box is a steel ball, turned up at the center of a steel shaft, which is roughly in the shape of a double cone, with the bases of the cones against the ball. The steel ball fits snugly into small zonal bearings in the spectrograph box, one of which is adjustable, the two forming a socket for the ball with its center in the plane of dispersion of the spectrograph. The ends of this shaft and of the two others mentioned below, all of which are normal to the plane of dispersion, are securely bolted to the supporting cradle described below. For the upper support near the slit-head, a second steel shaft tapering from the middle toward each end

is connected with the spectrograph box by a gymbal joint, consisting of two pins or solid cylinders crossing at right angles, and each passing normally through the center of the shaft. The larger pin or cylinder passes through a slot in the steel supporting axle into which it is fastened by the second pin which also serves as a bearing about which the larger pin may rotate. This larger steel cylinder is mounted with its axis in the line joining the two supports and fits at either end into cylindrical bronze bearings in the spectrograph box in the plane of dispersion. In these bearings the steel cylinder may rotate or slide longitudinally, thus permitting automatic adjustment of the distance between supports with temperature change and giving all the freedom of a ball and socket joint. The two supports acting together cannot cramp the box in any manner; but the combined restriction of these two supports leaves the box free to rotate about an axis joining them. Accordingly a steel shaft, passing through the open frame not far from the prism box carries two small guides, which may be adjusted to bear against two opposite points especially reinforced in the triangular sides of the spectrograph box. In Plate IX, the bearing point of the guide on one face of the box is easily located at the center of the black circle near the base of the prism. When the plane of dispersion is vertical the guides carry no weight, and the spectrograph box is resting entirely upon its supports. In any other position one of the guides carries a fraction of the weight of the box.

In the above system of support the cross section of metal across which heat may be conducted from the spectrograph box to the supporting cradle is a minimum. The two zonal bearings at the lower support have a combined area of approximately one-eighth of a square inch. The upper support is connected with the spectrograph by a three-sixteenths-inch pin only, and the guides are practically points bearing upon a very small area. Very little temperature conduction occurs at these points.

Finally, this system of attachment of the box to the supporting cradle has been found most convenient in effecting the adjustment of the instrument with reference to the telescope.

THE SUPPORTING CRADLE.

The supporting system is similar to that used at the Lick Observatory in connection with the new Mills Spectrograph; but considerable modification has been introduced to provide for the support of the three steel shafts and the guiding microscope. The general form of this part of the instrument is well shown in Plate VI, but may be briefly described.

A rigid cast iron ring bolted securely to the spider of the focussing mechanism of the telescope carries four symmetrical bosses, the chord joining each pair of which is parallel to the plane of dispersion at a distance of six and a half inches. To the face of each of these bosses is fastened a two- by two-inch T-beam. Each pair of these beams which is in a plane parallel to the plane of dispersion, converges to a stiff bronze casting, which supports one end of each of the two lower transverse axes. A well braced cross piece of cast iron connecting each pair of T-beams at a suitable point furnishes support for the end of the steel axis of the upper support. The three steel shafts together with the supports of the guiding telescope furnish a rigid connection between the two pairs of T-beams forming the truss. An additional element of rigidity at right angles to the plane of dispersion is furnished by a fifth T-beam, supported like the others on a boss on the ring casting but as far as possible from the plane of dispersion and converging to the bronze casting supporting the end of the steel shaft of the lower spectrograph support, on the side farthest from the polar axis of the telescope.

This supporting cradle is found to be rigid enough to support the spectrograph box, with temperature case, all together about one hundred and fifty pounds, with a negligible flexure effect.

THE SLIT-HEAD.

The slit-head is patterned after that of Keeler's Allegheny Spectrograph of 1893, with the usual reflecting slit jaws first used by Huggins. The following modifications, in addition to the totally reflecting prisms and prism mountings of the comparison, have been introduced:

Adjustable stops have been provided to prevent absolute closure of the slit jaws, thus protecting

the edges of the slit from damaging pressure and making possible the use of a slit with very sharp edges. The microscope behind the slit carries only a totally reflecting prism and a lens. The image of the slit may be observed with or without an eye-piece at a convenient point near the guiding microscope. The use of a long tube is thus avoided.

COMPARISON APPARATUS.

The spark comparison apparatus is modelled after that devised by Wright for the Mills spectrograph. However, instead of single pairs of terminals, two drums, as used by Frost, are employed, each carrying six sets of points. It is thus possible to bring fresh terminals into play, in case the pair in use fails to perform. Cylinders of the elements used for the spark are ground and pointed in our own shop, and are mounted in a manner calculated to facilitate adjustment. The coil, capacity, and self inductance are mounted on the telescope near the slit head, thus avoiding the inconvenience of carrying a high potential circuit across the floor, or on the pier and telescope axes.

The element used in the spark during the first year was titanium, partly because the activity of this element in the spark was of advantage in connection with the smaller coil then in use. With the purchase of a larger coil experiments were made with various elements and alloys, including iron, titanium, chromium, manganese, copper, nickel, lead, silver, cobalt, bismuth, alloys of iron with titanium, manganese, chromium, silicon, vanadium, molybdenum, and other miscellaneous combinations. Titanium proves to be the best single element, notwithstanding its weak regions in the neighborhood of $\lambda\, 4200$ and $\lambda\, 3850$. With plates sensitized up to $\lambda\, 6300$ it is also as good as any element that I have tested. Some of the alloys tested furnish a better distribution of lines, and the best among these are combinations of equal parts of iron and titanium, iron and chromium, and iron and molybdenum, with relative merit in the order given. For red sensitive plates a thin stain of filter yellow K on the ground glass mat between the comparison source and slit proves useful in bringing out comparison lines in the yellow, orange and red regions of the spectrum.

The frequent introduction of the comparison light, so easily effected with this type of comparison apparatus, distributes the exposures upon the reference lines throughout the exposure on the star and makes possible necessary allowance for interference by passing clouds. It is our practice to introduce the comparison spectrum at intervals of one minute for exposures of less than ten minutes; at intervals of not more than two minutes for exposures of not more than thirty minutes duration; at intervals of not more than five minutes for exposures of an hour or less; and at intervals of not more than ten minutes for exposures of greater duration than one hour.

GUIDING MICROSCOPE.

The guiding microscope, mounted with its axis in the plane of dispersion of the spectrograph, extends out on the side away from the plate holder. A small forty-five degree prism, three inches above the slit-head, reflects the star's light from the inclined speculum slit jaws into a small microscopic objective, which brings both slit and star image to a focus in the same plane before a direct vision eye-piece. A prismatic eye-piece may be substituted for the direct vision ocular at the observer's convenience. This simple guiding microscope has been adopted in preference to more convenient forms involving loss of light, in order to economize light in the observation of faint stars. For the observation of stars at considerable zenith distance an ethyl violet screen is inserted in front of the eye-piece, cutting out the green and yellow rays and revealing the star's blue light as displaced by atmospheric dispersion.

TEMPERATURE CASE.

The temperature case of the type used by Campbell, encloses the whole spectrograph box, including the slit-head. The main compartment includes the box up to the slit-head and comparison drum. A second small compartment covers the slit-head and comparison drums, with a small aperture to admit the star's light. The external layer of the temperature case is of one-half inch enameled pine. Inside of this is a ⅜-inch layer of waste, then 1-16 inches of wood fiber, and inside of this in the case of the main compartment a ¼-inch air space and a second 1-16-inch layer of wood fiber enclose the air space of 1½ inches

about the spectrograph box. In addition a heavy felt jacket is buttoned over the brass spectrograph box as a further insulation against local heating. Distributed uniformly over the interior of the main compartment of the temperature case is a heating circuit, comprising one hundred and thirty-eight feet of No. 27 German silver wire, strung at intervals of approximately an inch. The heating current, which rises to a maximum of three fourths of an ampere, is regulated by a mercurial thermostat with its bulb mounted on the outside of the spectrograph box near the prism. The bulb of the thermostat has an internal diameter of one fourth of an inch and is eight inches long. The capillary is one fiftieth of an inch in diameter and ten inches long and is open at the top. This instrument proves very efficient. After a little experience the observer at the beginning of the night can set the movable platinum wire which completes the themostat circuit near the top of the mercury column, and this adjustment needs no further attention during the night.

A small fan motor mounted in the upper part of the main compartment of the temperature case serves to produce circulation of air. This motor is governed by a battery rheostat on the outside of the temperature case near the observer.

Two thermometers graduated to tenths of a degree Centigrade are mounted in parallel with the stem of the thermostat. The bulbs of these thermometers are mounted as near as possible to the prism, one outside and the other inside of the prism box. The stems of all these thermal instruments are viewed through a long window of double glass cut in the side of the temperature case.

The smaller compartment of the temperature case about the slit-head is readily removed. The main compartment divides into three sections, one of which covers the plate holder and the lower end of the spectrograph. This section of the box is also easily removed to permit examination of the collimation of the spectrograph as well as visual observation of spectra. The remainder of the main compartment of the temperature case divides along the lines joining the supporting shafts of the spectrograph and on these shafts the temperature case is supported.

AUXILIARY APPARATUS.

OUTSIDE TEMPERATURE CASE.

The large temperature case, designed by the writer and described else where in this volume, encloses the spectrograph during the day and facilitates greatly the control of temperature about this instrument. At night when work is begun the temperature inside of the spectrograph temperature case, which is not removed or opened for airing, is usually a degree or so above the outside temperature and the prism is kept at essentially the same temperature throughout the day and night. Thus satisfactory temperature conditions are obtained without exposing the spectroscope to dust and air.

MEASURING ENGINE.

The measuring engine is well shown in Plate X. It was designed by the writer and was constructed by the J. A. Brashear Company. It combines the better features of the Toepfer and Gaertner engines and represents a compromise between the light construction of the former and the massive design of the latter type.

The more important new features embodied in the design of this engine may be briefly enumerated. The back-lash of the screw is taken up by a spiral clock spring mounted at the end of the bed of the engine. The secondary plate carriage may be moved by hand into any position and may be taken out and reversed to reverse the plate for the elimination of personal equation error. A pair of mirrors reflect the micrometer and index into the observer's right eye thus obviating the necessity of averting the eyes and head to read each setting of the plate carriage. Provision is made for the rotation of the microscope about an axis parallel with the axis of the screw. This makes it possible to secure small adjustment of the spectrum up and down in the field and is of convenience especially in connection with the interrupted reticle. The reticle holder is made removable to permit of the use of several types of reference lines in the ocular field.

Of the various reticles used, the single vertical line interrupted at the star spectrum has proven most satisfactory. In the preparation of such reticles on glass some experience has been gained

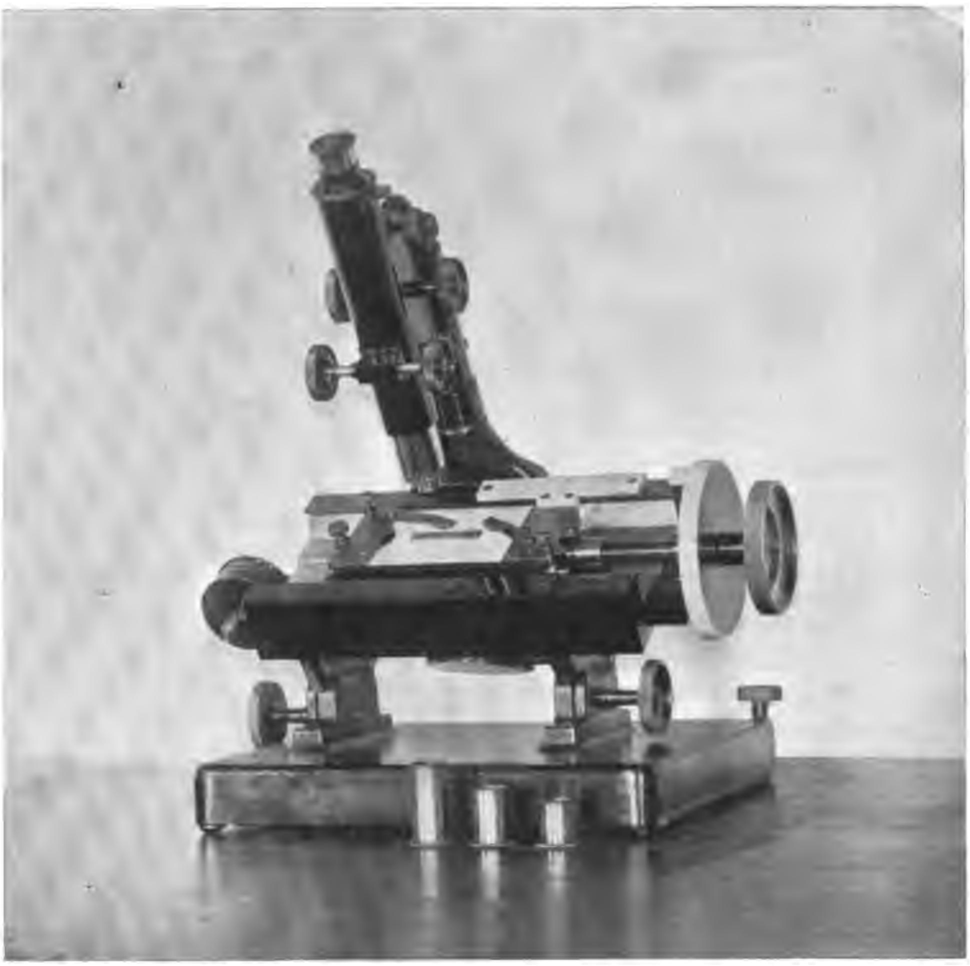

PLATE X. MEASURING ENGINE NO. I.

which may be of use to others. Four methods were tried all of which could doubtless be made successful. These methods include etching with hydrofluoric acid, ruling with a diamond point, photographic reduction from a drawing in black and white and direct photography of comparison lines with the spectrograph itself. The first method was used by the J. A. Brashear Company but nothing usable was obtained. Many ruled reticles were made by the writer upon crystal cover glass using the moving table of a milling machine to space the lines and the interruption. These reticles were very successful, the sharp black ruling proving if anything too fine for use with a one inch eye-piece. However, because of the slight optical effects at the edge of such rulings on glass futher experiments were made with the photographic method.

As no suitable photographic apparatus was available attempts to reduce a drawing on paper were not successful, though undoubtedly this method will give good results. The interrupted reticles which we are using were made according to the fourth method noted above. With a very narrow and long slit the comparison spectrum was exposed in the usual manner upon a plate of the finest grain. From this spectrogram of the comparison reticles were cut out with a glass cutter and mounted in the microscope reticle holder with some well defined sharp line in the center of the field. The length of the interruption in this line was controlled by the usual diaphragms in front of the spectroscope slit and may be made of any desired length. Several reticles were made, suitable for use with different powers. Thus with the spectrograph itself permanent reticles were prepared with which settings on the star lines can be made with an accuracy not inferior to that obtained with the spider thread. And in addition the advantage is secured of full visibility of the line while the setting is being made. Especially in the case of narrow sharp lines is this consideration important.

The screw of this measuring engine, developed by our own Instrument Maker, Mr. H. J. Colliau, seems to possess a remarkable accuracy. The pitch is one-half of a millimeter, and a movement of the plate carriage of three and one-fourth inches is provided for. Studies of the periodic error indicate that in this respect this screw compares favorably with the best screws that are in use in engines of this type. The correction formulae, to be applied in kilometers per second to any reading at Hγ for our spectrograph as well as the value of a given interval on three well distributed sections of the screw are given in the accompanying table, where "A" is the position angle of the micrometer head measured from a cross point of the error curve.

Section of Screw	20 R — 30 R	80 R — 90 R	150 R — 160 R
Correction Formula	+ 0.14 KM sin A	+ 0.04 KM sin A	— 0.15 KM sin A
Value of the distance between reference points	0.53479 R	0.53471 R	0.53483 R

It will be noted that there is a progressive change in the correction formula along the screw, and this led to a suspicion that the ways of the engine were convex or concave. This was investigated with a dial micrometer in combination with our milling machine and was found to be the case. But the maximum correction that can ever arise from the periodic error of this screw, even as modified by the inaccuracy of the ways, need not be considered in any work for which the engine was designed or intended.

The measurement, reduction and discussion of the spectrograms obtained with this spectrograph are now being carried on as opportunity permits. Results will appear from time to time in these publications.

June, 1912.

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY FROM AUGUST 16, 1909, TO JANUARY 1, 1912.

By WALTER M. MITCHELL.

The seismological equipment of this observatory was installed during the summer of 1909. The instruments were set up in the month of August in that year, and since that time have been in continuous operation. A description of these instruments has been given elsewhere; as stated there the equipment consists of the following:

Two Strassburg 100 kg. Tromometers by Bosch. These are so mounted that one gives the east and west component of the motion produced by the disturbance, while the other gives the north and south component.

One Wiechert Horizontal Seismograph, with steady mass of 100 kg. by Spindler and Hoyer. This is so mounted that the east and west, and north and south components are recorded.

One Wiechert Vertical Seismograph with steady mass of 80 kg. by Spindler and Hoyer.

The seismograph room (Plate V) is in the basement of the observatory building, the instruments being about 2 meters below the surface of the ground. On account of the situation and contruction of this room its temperature varies but slightly. The average daily variation is less than 3.0°F., occasionally however the variation is as great as 5.5°, but this latter figure is rarely exceeded. All the instruments are mounted on the same pier which is of concrete, approximately rectangular in shape, the dimensions being 3.1 by 3.6 meters; the longest dimensions being east and west. The pier has a depth of 1.3 meters, and is wholly isolated from the rest of the building.

The observatory is situated on the outskirts of the city of Ann Arbor, upon a hill about 1.5 km. in a north-east direction from the center of the city. The surface geological formation of this region is glacial till, consisting of coarse sand and clay with gravel and boulders to a depth of 40 meters or more.

There are two railroads in the vicinity; the tracks of one of these are directly north of the observatory at a distance of about 0.5 km. The vibrations caused by passing trains are distinctly visible on the seismograph records, and at times can easily be confused with microseismic tremors of small intensity. The other railroad is about 1.5 km. distant from the observatory and probably causes no disturbance.

As the observatory is stituated on the outskirts of the city, there are no street car lines in the vicinity and the wagon traffic is a minimum; hence from the point of view of seismology the situation is quite satisfactory.

The following table gives a list of the earthquakes that have been recorded at this observatory during the period from August 1909 to January 1912.

Column I gives the serial number of the shock. Remarks relative to the peculiarities of the shock as recorded follow the table, similar numbers referring to similar shocks.

Column II gives the date on which the shock was recorded.

Column III gives the component, and the instrument with which it was recorded. B-EW and B-NS, indicating the east and west, and north and south components respectively of the Bosch Strassburg Tromometers. Similarly W-EW and W-NS indicate the east and west and north and south components recorded with the Wiechert instrument.

Columns IV, V, VI, VII, VIII, and IX, give the recorded times of the phases of the shock. All times given in this account are Central Standard Time, midnight to midnight; to obtain Greenwich civil time add six hours.

The notation at the heads of these columns is practically that of the Göttinger system, in which,

P=First preliminary tremors.

S=Second preliminary tremors.

L=Long waves. (Principal portion of shock).

M=Greatest motion. (Time of maximum amplitude).

K=End of long waves.

F=End of visible disturbance.

* and † indicate that the beginning of the phase is well defined, or gradual, respectively.

Column X gives the maximum amplitude; that is the greatest excursion of the recording point from the zero line, measured in millimeters.

Column XI gives the mean of the distances in megameters as computed by the Laska formulae.

$\Delta = (S - P - I)$.

$\Delta = 1/3\ (L - P)$.

$\Delta = 1/2\ (L - S + I)$.

When the values of Δ given by these formulae agree, the computed distance has been considered accurate, and is so indicated in the remarks.

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1909		h m	h m	h m	h m	h m	h m	mm.	mgm.
1	Aug. 16	B—EW	1 2.6*	1 8.3	1 14.5†	1 16.3	1 21.7		0.8	4
		B—NS	1 3.9†		1 14.9†					
2	Aug. 31	B—EW	5 52.5*	6 5.9†	6 8.5†	6 9.0	6 10.7	6 25	0.7	3
		B—NS	5 52.4*	6 5.4†	6 9.1†	6 9.3	6 13.0	6 27	0.9	
3	Sept. 8	B—EW	10 58.1	11 5.6	11 15.6	11 19.7	11 20.3	11 47	0.9	6
		B—NS	10 57.1	11 5.8	11 15.9	11 19.8	11 20.7	11 50	0.6	
		W—NS	10 59.4		11 17.0		11 22.0	11 34	0.3	
4	Sept. 19	B—EW			14 41.5†	14 42.7	14 43.5	14 47.0	0.9	
		B—NS			14 42.5†	14 43.3	14 43.9	14 49.2	0.2	
5	Oct. 3	B—EW			14 59.7	15 1.4	15 1.8	15 4.9	0.4	
		B—NS			14 59.7	15 1.3	15 3.8	15 6.3	0.2	
		W—EW			14 59.8		15 3.5			
		W—NS			14 59.9		15 2.0			
6	Oct. 18	B—EW	2 35.2		2 39.3†	2 40.3	2 42.3	2 52	0.5	1.3
		B—NS	2 35.1		2 39.3†	2 40.5	2 44.5	2 56	0.6	
		W—EW			2 39.6*		2 42.2	2 49		
		W—NS	2 33.6		2 38.5*			2 44	0.3	
7	Oct. 20	B—EW			18 33.5†		18 50.8	18 59.4		
		B—NS			18 37.3†		18 53.8	19 1		
8	Oct. 29	B—EW			1 4.6†		1 8.1	1 9		
		B—NS		1 1.7	1 3.3*		1 6.8			
		W—NS		1 2.0	1 3.7		1 5.2	1 11		
9	Oct. 31	B—EW	16 29.1*	16 31.3†	16 35.7*	16 42.8	16 45.1	17 25	3.0	2.1
		B—NS	16 29.2*	16 32.1†	16 35.9*	16 41.9	16 42.5	17 24	2.5	
10	Nov. 10	B—EW			0 39.0†			1 25		
		B—NS			0 35.0†			1 30		
11	Dec. 9	B—EW			10 32.0†		11 3.0		0.5	
		W—EW			10 32.0†		11 1.0			
		W—NS			10 36.5†		10 49.5			
	1910									
12	Jan. 1	B—EW	5 6.9*		5 11.5*	5 16.7	5 39.3	6 19	>100.0	1.5
		B—NS	5 7.2*		5 11.7*	5 24.8			29.0	
		W—EW	5 7.7*		5 11.8*	5 16.5	5 23.8	5 58	8.0	
		W—NS	5 7.3*		5 11.5*	5 20.6	5 32.0	5 56	7.0	

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1910		h m	h m	h m	h m	h m	h m	mm.	mgm.
13	Jan. 22	B—EW	2 55.6	3 1.0	3 9.1†	3 13.3	3 14.8	4 5	50.0	5.1
		W—EW	2 55.0	3 1.6	3 11.5†	3 14.5	3 16.0	3 55	6.0	
		W—NS	2 56.0	3 2.8	3 13.0†	3 15.5	3 17.0	3 52	4.0	
14	Jan. 23	B—EW	12 56.1*	13 2.0*	13 9.8		13 15.3	13 39	2.0	4.7
		B—NS	12 56.4*	13 2.3*	13 10.3		13 17.7	13 30	2.0	
		W—EW	12 55.5*	13 1.5*	13 10.0		13 14.5	13 20	1.0	
		W—NS	12 55.5*	13 1.4*	13 9.5		13 17.0	13 22	1.0	
15	Feb. 28	B—EW	15 14.6†	15 22.7†	15 32.6†	15 33.1	15 33.3	16 5	2.3	6.0
		B—NS	15 15.3†	15 24.1†	15 33.5†	15 34.6	15 34.9	16 4	1.0	
		W—EW		15 25.0	15 33.0	15 33.5	15 34.0	15 47	0.6	
		W—NS		15 25.0	15 33.5	15 34.3	15 35.0	15 57	0.8	
16	Mar. 11	B—EW	1 0.5†		1 8.0		1 15.2		0.1	2.5
		B—NS	1 0.5†		1 8.0		1 15.0		0.2	
		W—NS	1 0.5†		1 8.0		1 14.0		0.3	
17	Mar. 18	B—EW	18 24.8		18 28.2		18 32.2	18 38.0	0.4	
		B—NS	18 24.6		18 27.5	18 28.6	18 30.5	18 38.5	0.7	
18	Mar. 30	B—EW			11 56.5	12 2.0	12 3.3	12 28.3	2.0	
		B—NS			11 54.7		12 3.3	12 21.5	0.2	
		W—EW			11 56.0		12 2.5			
		W—NS			11 54.0		12 2.0	12 10.0	0.1	
19	April 11	B—EW		18 45.1	18 48.3			19 38	1.0	
		B—NS	18 40.9	18 46.8	18 49.9			19 37	1.0	
		W—NS	18 41.0	18 46.8	18 50.0		18 52.0	19 36	0.8	
20	April 26	B—EW	19 38.4	19 41.9	19 44.8		19 46.3	20 4	0.3	2.0
		B—NS	19 38.6		19 45.5		19 45.8	20 4	0.1	
21	May 4	B—EW	18 37.0	18 40.9	18 45.5		18 54.5	19 9	0.5	2.6
		B—NS	18 37.2	18 41.1	18 46.8		18 48.7	19 8	0.6	
		W—EW	18 38.2	18 41.8	18 45.4		18 49.0	18 55	0.2	
		W—NS	18 38.0	18 41.7	18 45.4		18 49.2	18 59	0.3	
22	May 13	B—EW	2 7.8†	2 14.5*	2 24.4*	2 36.0	2 36.3	4 3	5.0	5.7
		B—NS	2 7.5†	2 14.3*	2 24.2*	2 34.0	2 42.9	3 42	3.0	
		W—EW	2 8.3†	2 14.3*	2 24.2*	2 33.3	2 45.0	3 29	2.0	
		W—NS	2 7.0†	2 14.0*	2 24.0*	2 32.5	2 42.0	3 47	1.8	
23	May 20	B—EW	6 16.7*	6 19.9*	6 23.3	6 24.9	6 25.9	6 38	2.0	2.2
		B—NS	6 16.7		6 24.4		6 25.9	6 37	0.5	
24	May 22	B—EW	0 36.4	0 47.0*	1 5.3†		1 18.0	2 00	0.3	10.1
		B—NS	0 36.6*	0 46.7*	1 8.7†		1 25.7	1 33	0.2	
		W—EW	0 36.5	0 46.6	1 5.0		1 22.0	1 31	0.3	
25	May 30	B—EW	23 1.7*	23 6.6	23 13.3	23 26.6	23 27.8	23 57	1.6	3.9
		B—NS	23 1.5*	23 7.0*	23 14.2*	23 20.1	23 27.7	23 58	3.0	
		W—EW	23 1.5*	23 6.4*	23 13.6†	23 26.4	23 28.0	23 50	0.7	
		W—NS	23 1.6*	23 6.4						
26	June 1	B—EW	0 21.5		0 56.9	1 1.0	1 7.0	2 19.	0.3	
		B—NS			0 56.0		1 13.0		0.1	
		W—EW			0 57.0	1 0.0	1 2.0	1 57	0.2	
27	June 16	B—EW	0 50.6*		1 0.3	1 1.7	1 40.3	3 13	10.0	3.1
		B—NS			1 0.0	1 22.6	1 25.7	3 9	1.0	
		W—EW	0 50.4*		1 0.0	1 0.4	1 41.0	3 5	2.5	
28	June 29	B—EW			2 46.3		3 10.4	3 21	0.2	
		B—NS			2 46.7		3 10.7		0.1	
29	June 29	B—EW			5 43.1	5 53.4	5 54.7	6 39	0.9	
		B—NS			5 42.7		6 3.7	6 19	0.1	
		W—EW			5 43.0		5 46.0	6 2	0.1	

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1910		h m	h m	h m	h m	h m	h m	mm.	mgm.
30	July 3	B—EW			3 26.3		3 32.9	3 38	0.2	
		B—NS			3 26.0		3 33.7	3 39	0.1	
31	July 6	B—EW	22 55.3	22 57.3	22 58.6	22 59.3	22 59.8	23 20	16.0	1.3
		B—NS	22 54.5	22 57.4	22 58.7	22 59.1	22 59.4	23 21	5.0	
		W—EW	22 55.1	22 57.1	22 59.9	22 59.0	23 0.0	23 9	4.0	
		W—NS		22 57.1	22 57.7	22 58.0	22 58.3	23 4	3.0	
32	July 17	B—EW	4 11.9	4 14.3	4 16.8		4 18.7	4 33	0.6	
		B—NS			4 16.1		4 18.7	4 30	0.7	
33	Aug. 4	B—EW	19 38.0*	19 45.3†	19 50.3	19 51.7	19 53.3	20 42	4.0	3.8
		B—NS	19 38.0	19 42.7†	19 48.7	19 49.2	19 52.2	20 26	7.0	
		W—NS			19 48.5	19 49.0	19 53.0	19 59	3.2	
34	Aug. 11	B—EW	10 36.5	10 41.0	10 44.8	10 45.6	10 45.9	11 8	7.0	2.9
		B—NS	10 36.1	10 40.5	10 44.3	10 45.2	10 48.3	11 7	0.5	
		W—EW		10 40.5	10 44 2	10 45.0	10 46.3	10 53	1.3	
		W—NS			10 44.5		10 48.3	10 59	0.2	
35	Aug. 21	B—EW			24 2.9		24 10.4		1.0	
		B—NS	23 55.1		24 3.0		24 8.5	24 30	0.5	
36	Sept. 6	B—EW	14 24.0		14 46.0			15 15	0.1	
37	Sept. 7	B—EW			2 12.0		2 37.0	3 0	0.2	
38	Sept. 7	B—EW			4 57.0		5 30.0		0.2	
39	Sept. 8	B—EW	19 23.9	19 31.9	19 42.4	19 42.5	20 0.0	20 51	4.0	5.5
		B—NS	19 23.9	19 32.1	19 42.0		20 2.0	20 50	0.8	
		W—EW			19 44.8				0.4	
		W—NS	19 23.8	19 32.0	19 42.0		20 0.0	20 40	0.4	
40	Sept. 23	B—EW	21 38.5	21 43.2	21 49.6		22 7	22 50	1.0	3.7
		B—NS	21 38.3	21 43.3	21 49.5		22 1	22 50	0.7	
		W—EW			21 49.1				0.8	
		W—NS	21 38.3	21 42.9	21 49.9		22 6	22 50	0.4	
41	Oct. 4	B—EW	17 10.9		17 19.3	17 20.2	17 21.5	17 42	4.0	2.8
		B—NS	17 11.3		17 19.8	17 20.7	17 22.2	17 52	1.0	
		W—EW			17 19.1	17 21.1	17 21.3	17 24	2.5	
		W—NS	17 10.7		17 19.2	17 20.0	17 21.5	17 43	1.1	
42	Oct. 15	B—EW			20 32.0		20 36.7		0.2	
43	Nov. 6	B—EW	14 37.8†	14 42.3†	14 48.5*	14 49.3	14 52.3	15 37	20.0	3.3
		B—NS	14 37.7†	14 43.0†	14 48.7*	14 52.2	14 54.3	15 42	13.0	
		W—EW	14 37.7†	14 42.9†	14 48.8*	14 53.0	14 53.5	15 15	4.1	
		W—NS	14 38.0†	14 42.1†	14 48.6*	14 52.2	14 54.3	15 33	6.0	
44	Nov. 9	B—EW	0 21.0†	0 31.4†	1 0.4	1 24.8	1 30.3	3 0	1.0	
		B—NS		0 30.7	1 16.8			2 37	0.2	
		W—EW			0 57.2	1 24.8		2 27	0.2	
		W—NS		0 31.8†	1 16.5	1 19.0		2 35	0.1	
45	Nov. 24	B—EW	22 59.0	23 10.4	23 38.7	23 40.2	23 50.2	25 10	2.3	10.2
		B—NS	23 0.1		23 39.1	23 40.6		25 23	0.1	
		B—EW	23 0.3	23 10.6	23 37.0	23 40.0	23 51.1	25 35	2.0	
46	Dec. 10	B—EW			4 26.8	4 28.5	4 32.9	4 56	1.5	
		W—EW			4 25.0	4 28.6	4 32.0	4 58	0.5	
47	Dec. 13	B—EW	6 31.9	6 39.6	6 42.9	6 43.9	6 45.0	7 24	5.0	3.1
		B—NS			6 30.9	6 37.8	6 44.8	7 24	1.1	
		W—EW	6 31.1	6 37.3	6 42.0	6 43.2	6 44.6	7 23	1.5	
		W—NS			6 32.1		6 45.0	7 19	1.0	
48	Dec. 16	B—EW	9 7.3	9 15.9	9 23.1		10 12.3	11 6	0.7	
		B—NS	9 4.7	9 16.2				10 50	0.3	
		W—EW	9 4.3	9 21.4	9 38.0		10 13.0	11 6		
		W—NS	9 4.1		9 56.0		10 30.0			

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	K	F	A	Δ
	1910		h m	h m	h m	h m	h m	h m	mm.	mgm.
49	Dec. 21	B—EW	4 36.2	4 38.4	4 42.2	4 44.2	4 49.0	5 0	0.3	2.0
		B—NS	4 36.7		4 43.8		4 47.0	4 55	0.4	
		W—EW		4 38.9	4 42.0		4 45.0	4 52	0.3	
		W—NS			4 44.3		4 47.0	4 50	0.4	
50	Dec. 22	B—EW			19 7.2		19 17.0	19 21	0.4	
		B—NS			19 6.6		19 16.6	19 21	0.2	
		W—EW			19 7.8		19 16.9		0.3	
		W—NS			19 7.3		19 15.9		0.1	
	1911									
51	Jan. 3	B—EW	17 38.7†	17 49.8	18 9.0	18 35.3	18 36.9	19 22	53.4	10.1
		B—NS	17 39.1	17 49.8	18 15.4	18 24.7	18 40.4	19 9	7.9	
		W—EW		17 50.2	18 9.4	18 24.0	18 35.6	19 23	9.3	
		W—NS	17 39.1	17 50.2	18 10.1	18 25.4	18 34.6	19 21	9.7	
52	Feb. 4	B—EW	22 29.9		22 36.3		22 41.9	22 51	0.8	2.3
		B—NS	22 29.9					22 53	0.4	
		W—EW	22 30.0		22 36.7		22 41.2	22 44	0.8	
		W—NS	22 30.0		22 36.8		22 40.2	22 43	0.2	
53	Feb. 18	B—EW	13 5.3		13 40.8		13 50.8	13 58	1.3	10.1
		B—NS	13 5.1		13 38.2		13 48.7	14 10	0.5	
		W—EW		13 25.0	13 36.3		13 50.0	14 7	0.4	
		W—NS			13 38.2		13 47.1	13 58	0.4	
54	April 10	B—EW	12 49.8	12 54.8	13 2.3		13 5.4	13 16	1.8	3.3
		B—NS	12 49.1	12 54.6	13 3.8		13 5.8	13 16	0.4	
		W—NS		12 54.6	13 4.0		13 5.3		0.1	
55	April 28	B—EW		4 5.7	4 8.1	4 8.3	4 10.5	4 21	0.8	2.0
		B—NS	4 0.2		4 6.9	4 7.1	4 7.8	4 12	1.0	
		W—EW				4 7.5	4 9.7		0.3	
56	May 4	B—EW	17 47.3	17 51.0	17 57.2	17 57.3	17 59.0	19 1	14.0	3.0
		B—NS	17 48.2	17 53.3	17 57.6	17 57.8	17 59.0	18 47	4.0	
57	May 9	B—EW			13 55.6		13 56.6	14 6	0.3	
		B—NS			13 55.3		13 56.2		0.2	
		W—EW			13 55.4		13 55.7		0.2	
58	May 9	B—EW			18 40.3		18 44.5	18 51	0.1	
		B—NS			18 38.7		18 42.3	18 49	0.1	
59	June 7	B—EW	5 9.0	5 14.3	5 19.9	5 25+	5 37.0	7 31	>90.0	3.6
		B—NS	5 8.8	5 14.0	5 18.8	5 26+	5 31.2	6 45	>90.0	
		W—EW	5 8.8	5 14.0	5 19.1		5 31.1	6 25	14.0	
		W—NS	5 8.9	5 13.8	5 20.1			6 2		
60	June 15	B—EW	8 40.1	8 44.5	8 50.4	9 5.0	9 26.3	10 18	4.0	3.4
		B—NS	8 39.9	8 43.2	8 53.0	8 53.2		10 13	6.0	
		W—EW		8 44.0	8 50.4	9 3.7	9 26.5	9 54	1.0	
		W—NS	8 39.0	8 44.1	8 49.5	8 53.0	9 21.1	9 47	3.4	
61	July 1	B—EW		16 16.4	16 18.8	16 19.0	16 19.2	16 34	4.5	1.5
		B—NS	16 10.5	16 14.1	16 15.9	16 16.5	16 17.5	16 45	8.0	
62	July 11	B—EW	22 30.9							
		B—NS	22 27.9	22 38.5						
63	Aug. 16	B—EW	17 1.1	17 11.0	17 34.8	17 51.1	18 9.1	18 50	1.1	10.1
		B—NS		17 12.1*	17 36.3	17 51.8	18 19.4	18 40	3.0	
		W—EW		17 11.0	17 35.1	17 51.1	18 17.1		0.6	
64	Aug. 17	B—EW	5 4.4	5 8.4	5 10.3	5 11.4	5 14.0	5 20	0.6	1.7
		B—NS	5 5.3	5 7.4	5 10.0	5 10.3	5 11.9	5 24	0.8	
		W—EW			5 8.3	5 9.6	5 11.4		0.1	

NO.	DATE	COMPONENT INSTRUMENT	P	S	L	M	K	F	A	Δ
	1911		h m	h m	h m	h m	h m	h m	mm.	mgm.
65	Sept. 12	B—EW			21 29.5		21 38		0.2	
		B—NS			21 29.0	21 36.7	21 43		0.2	
66	Sept. 16	B—EW	21 51.0	21 58.5	22 6.5	22 9.6	22 10.5	23 0	11.5	
		B—NS	21 50.0		22 5.0	22 6.3	22 20.0	22 7	1.5	5.1
		W—EW	21 49.2	21 58.1	22 6.3	22 8.0	22 10.8	22 44	1.3	
		W—NS			22 6.0		22 9.8			
67	Sept. 21	B—EW	23 10.3	23 16.7	23 24.2	23 25.1	23 26.5	23 41	2.9	
		B—NS	23 10.5	23 15.8	23 23.6	23 24.2	23 26.4	23 44	2.5	4.5
		W—EW		23 15.7	23 24.1		23 25.2	23 34	2.6	
68	Oct. 6	B—EW	4 21.6	4 26.1	4 28.6	4 33.6	4 35.6	4 46	17.0	
		B—NS	4 22.0	4 26.5	4 34.5	4 37.6	4 39.7	5 10	4.0	3.0
		W—EW	4 20.9	4 25.3	4 31.6	4 32.7	4 34.3	4 45	3.2	
		W—NS	4 20.9	4 25.3	4 32.0		4 37.6	5 0	2.0	
69	Oct. 26	B—EW			8 28.5		8 37.0			
70	Nov. 7	B—EW			0 11.8	0 12.4	0 13.3	0 22	0.9	
		B—NS			0 12.0		0 13.7	0 21	0.3	
		W—NS			0 11.7		0 13.7	0 21	0.1	
71	Nov. 18	B—EW			1 52.0	1 53.0	1 53.4	2 4	1.3	
		B—NS		1 50.4	1 51.1		1 53.6	2 4	0.5	
72	Nov. 20	B—EW		8 2.0	8 6.1		8 13.1	8 20	1.8	
		B—NS		8 1.5	8 8.5	8 9.5	8 10.7	8 17	2.0	
		W—NS			8 8.0		8 10.3	8 12	0.4	
73	Nov. 25	B—EW			1 46.7			1 51	0.6	
		B—NS			1 47.0	1 47.5	1 47.7	1 51	1.9	
		W—NS		1 46.0	1 48.0		1 49.0	1 50	0.1	
74	Dec. 16	B—EW	13 20.7*	13 26.0*	13 33.9		13 45.4	14 45	>46.0	
		B—NS	13 20.6*	13 26.0*	13 32.6	13 34.2	13 38.6	14 45	35.0	4.2
		W—EW			13 31.2		13 38.9	13 49		
		W—NS	13 20.7	13 25.8	13 31.3	13 33.9	13 38.9	14 9	12.0	
75	Dec. 20	B—EW			0 24.2		0 32.2	1 7	0.2	
		B—NS			0 23.6		0 34.6	1 0	0.1	
		W—EW			0 23.9		0 33.9	0 40	0.1	
		W—NS		0 18.1	0 23.9		0 32.9			
76	Dec. 23	B—EW	15 11.7	15 19.0	15 24.5		15 31.5	15 44	0.5	
		B—NS	15 13.3	15 16.1	15 22.1		15 31.2	15 44	0.4	4.3
		W—EW	15 16.8	15 20.3	15 22.8		15 30.8		0.1	
		W—NS	15 11.5	15 19.4	15 24.4		15 31.0	15 45	0.3	

REMARKS.

1. Motion almost entirely in E-W component. Period of vibrations 15—20 sec. at M. No record on Wiechert instruments.

2. Phases of shock are not well defined, hence P and S may be incorrect. No record on Wiechert instruments. Microseisms during the day.

3. Numerous microseisms of small intensity have preceded this shock. Faint traces of shock on W-EW. Times given for W-NS are uncertain.

4. The microseisms are numerous during the day. Times of phases of this shock are hence uncertain.

5. No preliminaries perceptible, movements of short duration.

6. P uncertain, S not perceptible.

7. A succession of long period waves of very small amplitude. Impossible to distinguish the phases. Barely perceptible on Wiechert records.

8. Microseisms during the day and preceding this shock, mask the phases. W-EW record is indistinct.

9. Record of Wiechert instrument is missing.

10. Motion consists of long slow waves of small amplitude. The phases are indistinguishable. Preceded by microseisms during the day.

11. The preliminary tremors are well marked, but it is difficult to identify them. Microseisms have preceeded this shock, and P may be obscured, P as given being in reality S. The distance is hence unreliable. The record consists of a series of pulses, lasting about 15 minutes. The pen of the E-W Strasburg pendulum moved entirely off the sheet, but this may be due to synchronism of the impulses and the period of the pendulum, as the W-EW does not indicate that the amplitude should have been sufficiently great to do this. B-N S record is incomplete as driving clock of drum stopped.

13. The phases of this shock are fairly distinct, hence the distance is reasonably accurate. B-EW record gives a series of strong waves lasting three minutes. B-N S instrument out of order. Wiechert records show long waves are of longer duration, the end of it not being clearly marked. Apparently no tremors preceded this shock.

14. This shock was a series of waves of small amplitude, period about 20 sec. M is not well defined. Distance is reasonably accurate.

15. Preliminaries are long drawn out and not distinctly marked. Duration of main waves is very short. Microseisms recorded on Wiechert records; these mask the time of P.

16. A very small disturbance, S not distinguishable. No record of shock on W-E W.

17. Principal movement in N-S component. It is uncertain which one of preliminaries is missing. Vibrations of small period and amplitude are superimposed on the long waves in N-S sheet. Not registered in W-E-W.

18. A series of waves of small amplitude, period about 25 sec. The phases are not well marked. Direction of shock probably mainly E-W.

19. The phases are not well marked. A succession of short period tremors beginning with M and continuing until 19 h 14 m, then changing with long period vibrations of small amplitude. Disturbance not registered on W-E W.

20. A small disturbance. Phases are not very distinct but the distance is probably accurate. Very slight traces of the disturbance on the W-N S record.

21. A small disturbance. The phases are not well defined.

22. A distinct shock, P not plainly marked. Distance is probably accurate.

23. Principal movement E-W. Recorded on Wiechert sheet, but times are unobtainable as signals were out of order. Distance probably accurate.

24. The record is typical of a distant shock. Not recorded on W-N S. Direction of Movement is E-W. Distance is reasonably accurate.

25. The W-N S record is not satisfactory. Evidently pendulum was not free. The long waves show short period waves superposed on them. Heavy tremors appear in E-W record 23 h 26 m to 23 h 27 m. Distance is probably accurate.

26. Probably a distant shock of small intensity. Long waves seem to be repeated at 1 h 20 m—1 h 25 m and again at 1 h 53 m—2 h 0 m. B-N S record is somewhat uncertain. Not recorded on W-N S.

27. S not distinguishable. Main shock consists of a series of separate pulses, the heaviest beginning at 1 h 0.3 m, lasting until 1 h 2.1 m. Then only small tremors until tremors of moderate amplitude begin at 1 h 26.0m; these have a period of about 25 sec. and continue until 1 h 29.3 m. Then another shock of greater amplitude from 1 h 32.6m to 1 h 34.2 m. Then a final shock beginning at 1 h 36.0 m lasting until 1 h 40.3 m, with period of 15 sec. and maximum amplitude of 6 mm. Direction of shock almost entirely E-W. Only very faint traces were observed in the W-N S.

30. A small disturbance, very faint traces in W-E W record.

31. A single shock of short duration, direction of travel probably S E-N W.

32. Very slight traces of this shock on the E-W Wiechert record.

33. Times of S are uncertain. Direction of movement mainly N-S. Time signals missing on E-W Wiechert.

34. This shock consists of a single impulse. Direction of movement nearly E-W.

35. A very feeble shock with two impulses.

Direction probably nearly N-S. Traces of this shock on the Wiechert record.

36. A very feeble shock, consists of small amplitude and short period waves, period of waves gradually lengthens.

38. Somewhat similar to microseisms, but period is longer (10 sec.). There are faint traces of this shock on the Wiechert record.

39. A single strong impulse in the B-E W record. The long waves are irregular with small amplitude (1.5 mm). The single pulse is not conspicuous on Wiechert record, hence this may be due to swing of pendulum on Strassburg apparatus.

40. Direction of movement nearly N-S. A curious movement of short period waves begins at 22 h 16.7 m (N-S), continuing for about 5 min. This begins about 3 min. later in E-W component.

41. Direction nearly N-S. Two impulses separated by about 1 min., followed by a few small amplitude vibrations, developing into the usual tail. N-S component probably stronger. Distance uncertain.

42. A very slight disturbance, not recorded on any other instrument.

43. Direction N W-S E. The preliminaries are faint. Two or more fairly distinct shocks followed by several of smaller intensity. Distance is reasonably accurate.

44. A long series of waves with period 10-15 sec. The phases are indistinguishable, the times given for them are probably incorrect.

45. Phases not clearly distinguishable, hence distance is uncertain. Major portion of record is a series of sine curves. Recorded on W-N S but time signals are uncertain.

46. Owing to continuous microseisms during the day, P and S can not be distinguished. Only very slight traces in N-S records. Times are somewhat uncertain owing to missing clock signals.

47. P and S very uncertain. Shock begins suddenly, in full force without any preliminaries in N-S components. This continues in a series of impulses.

48. A long series of tremors; phases cannot be distinguished, hence recorded times may be incorrect. W-E W times are probably the most accurate. Microseisms begin after this shock.

49. A small disturbance, phases not well defined.

50. A very slight disturbance, movement principally E-W.

51. This is the Turkestan Earthquake. The phases are quite distinct and distance is correspondingly accurate.

52. Small shock, waves of very short duration. Principally in E-W direction. Distance is uncertain.

53. Phases are not distinctly marked, hence times given may be incorrect. Shock consists mainly of slow waves of small amplitude.

54. A small disturbance. Time of L is uncertain. Only faint traces in W-E W record. Distance is uncertain.

55. A very small disturbance, consisting of a sharp impulse followed by tremors. Faint traces in W-N S record. Phases are not well marked, hence distance is uncertain.

56. A single strong impulse, followed by a long tail. Possibly a second impulse occurred 0.7 min. after the first, but this is not certain. Time signals not working perfectly, but B times are very close. Recorded on Wiechert instrument, but no times can be read.

57. A very small disturbance, no preliminaries visible.

58. A succession of waves of very small amplitude and period, not seen on Wiechert records.

59. This shock occured near the city of Mexico. Probably the heaviest shock recorded at this station. Both Strassburg pendulums swung off the sheets; hence M and maximum amplitude are unknown. Distance is somewhat uncertain. L should possibly be increased by about 2 min. Wiechert records are fair, but times are uncertain as in all severe shocks, as time signals are lost. W-N-S pen not free, hence this record is incomplete.

60. Preliminaries are fairly well marked, but the long waves are broken into groups, possibly an interference effect.

61. The California Earthquake. Preliminaries are not well marked. No trace whatever on Wiechert record; instrument apparently in good adjustment.

62. This shock begins with a group of sharp tremors (P), which last for about 1.5 min., then die out completely in the E-W component, but continuing in the N-S until 23 h, then both sheets show sinusoid curve of small amplitude. The phases are not distinguishable. No record on Wiechert instrument.

63. A long series of long period tremors. W-N S record is illegible. Phase L is not well marked.

64. P and S uncertain, a very feeble shock. The main waves consist of a single swing. Only the faintest traces on W-N S record.

65. A series of very irregular tremors of small amplitude. Not seen on Wiechert records.

66. Direction nearly E-W. Times of preliminary tremors are uncertain. W-N S record consists of a few isolated vibrations.

67. A small shock. Main waves are very irregular. W-N S record is illegible. Distance fairly accurate.

68. Earthquake occurred in Hayti. Phases cannot be clearly distinguished and determination of distance is not accurate. First portion of main waves are irregular, later portion regular and with short period (15-20 sec.).

69. A series of sinusoid curves visible only on B-E W.

70. No preliminaries visible. A small disturbance, tremors of short period.

71. Preliminaries not determined owing to continuous irregular tremors during the day. No traces of the shock on Wiechert record.

72. Phases are very uncertain owing to tremors during the day. Times of B-N S are probably the most accurate. No traces of shock in W-E W record.

73. A small disturbance. No preliminaries visible.

74. The Mexican Earthquake. A strong shock. Preliminaries are well defined. Pen on B-E W swung off sheet at 13 h 34.8 m, returning at 13 h 45.2 m. W-E W record is defective as pendulum was not free.

75.. A series of sinusoid curves, beginning and ending gradually.

76. The main waves consist of a series of sine curves. Preliminaries not well determined. Times given by B-E W and W-N S are probably the most accurate.

The equipment of this station affords a good opportunity for a comparison of the Wiechert and Bosch instruments.

The Wiechert Vertical Seismograph has so far proved generally unsatisfactory. During the period of which the observations are a record not a single disturbance was recorded. Even in the most severe (Mexican) shock of June 6, 1911, there was not the least trace of movement. Considerable time has been spent in attempting to adjust this apparatus but without much effect. Possibly the instrument is still out of adjustment, but as there is nothing in its design to indicate when it is in adjustment, our attempts have been confined to trial methods, the results of which have been only partially successful. Since the beginning of this year two very small records have been obtained. Apparently the instrument lacks sensitiveness.

Comparing the Wiechert Horizontal Siesmograph with the Strassburg Tromometers, the latter type of instrument has proven more satisfactory for the following reasons. It is decidedly more sensitive, and in practically all cases of near and distant shocks the records are more legible, and are probably more accurate. There has been very little recorded on the Wiechert instruments that has not been recorded also on the Bosch Tromometers. The reverse of this is however not true. Microseisms have been recorded many times on the Bosch instruments, of which there was not the slightest trace on the Wiechert instruments. The most serious fault of the Wiechert instruments, in addition to that already mentioned, is one of design. Namely that the earthquake record and the time signals are both made by the same recording point. If the shock is a severe one, the time signals become completely obliterated, and the times of the phases cannot always be determined. In addition the rate of the driving clock is so very irregular that the times cannot be estimated to within a quarter of a minute after an interval of five minutes.

In the beginning, the Bosch instruments were not completely adjusted, hence the periods of the

two pendulums differ considerably; the East and West being 14.5 seconds, and the North and South 9 seconds. These instruments have been used without damping, the object being to secure as large an oscillation as possible. The de-pendulum is certainly not an ideal one, for resulting from the design of the apparatus the damping effect increases with the amplitude of the swing, instead of remaining constant. It occurs to the writer that a more satisfactory de-

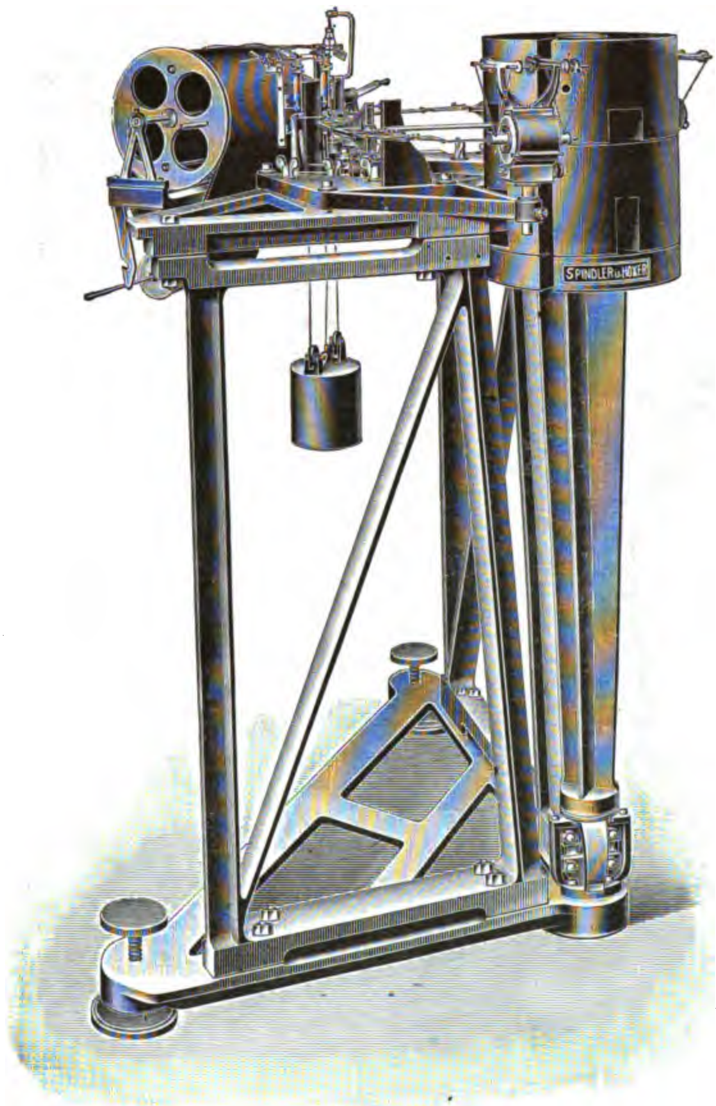

PLATE XI. THE WIECHERT HORIZONTAL SEISMOGRAPH

sirablity of this is obvious, but it is evident that it must be partially offset by the frequent loss in accuracy resulting from the impossibility of differentiating the phases of the shock owing to the continued swing of the undamped pendulum. The arrangement of damping the swing of the vice would be something in the nature of a small vane or disk attached to the pendulum in such a manner that the vane would move in a liquid of suitable density, the amount of damping being regulated by the size and position of the vane, or by the density of the fluid.

The period of vibration of the pendulum in the Wiechert Horizontal Seismograph is about 4 seconds. This instrument has been used with damping, the damping device seems to be satisfactory. The system of levers by which the motion of the steady mass is communicated to the recording point is rather complicated and apparently does not always perform satisfactorily. This is evidenced by the occasional absence of all traces of movement on the Wiechert record when shocks of moderate intensity have been recorded on the Bosch instruments. The two components of the Wiechert Horizontal Seismograph appear to be of unequal sensitiveness. In studying the record of microseisms it will be noted that when recorded by this instrument the record in the great majority of cases has been with the North and South component, and when recorded by both components the North and South record has been the stronger. Although this has been the rule, there have been exceptions to it, in which the East and West component was the stronger.

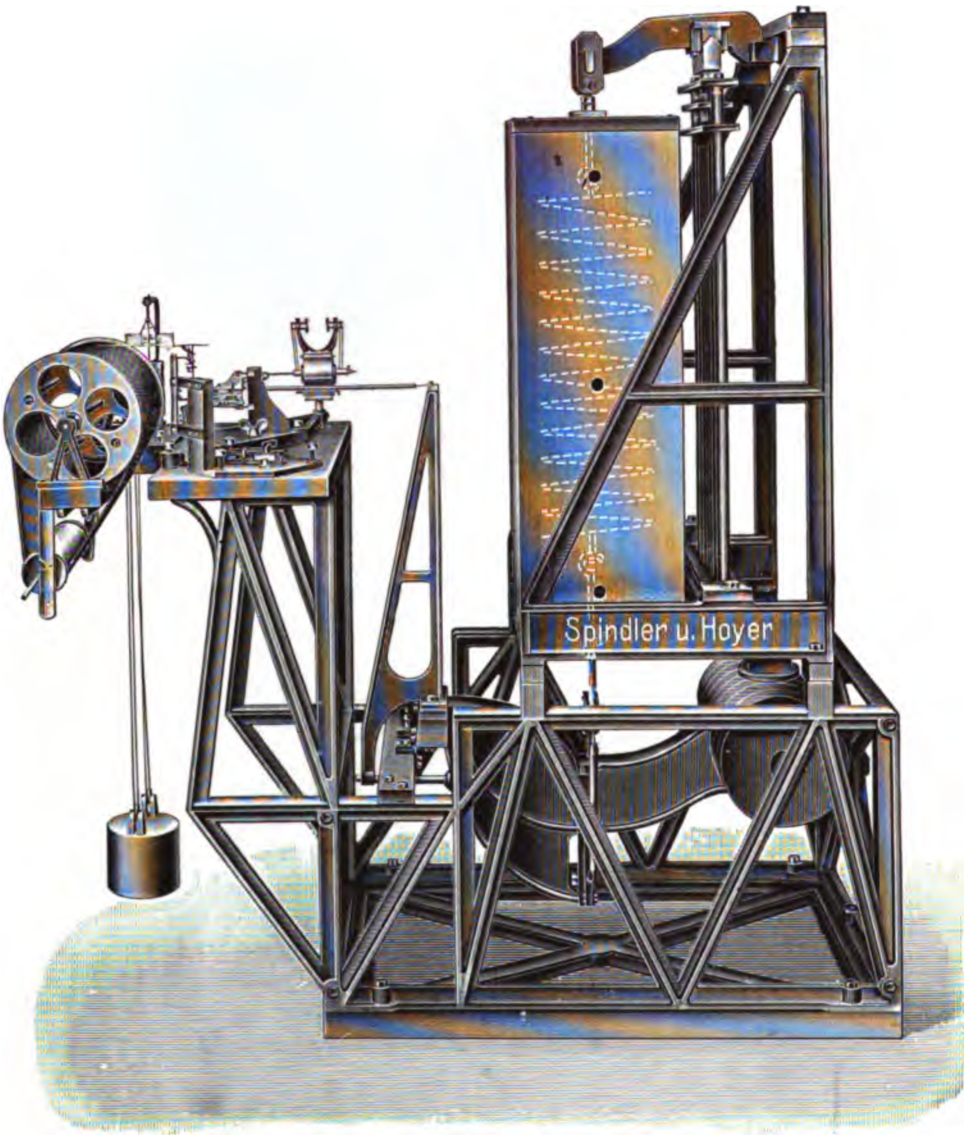

PLATE XII. WIECHERT VERTICAL SEISMOGRAPH.

The registration in all instruments is mechani-

cal, upon smoked paper. The rate of movement for the Bosch Tromometers is 15 millimeters to one minute. For the Wiechert instrument it is 10 millimeters to one minute. Other observers have noted the desirability of recording the times with an accuracy of a single second. It seems doubtful if it will be possible to do this in general. In some cases such accuracy may be occasionally reached, but in the great majority of cases the beginning of the movement is so gradual, and is frequently so completely masked by the vibrations of the pendulum, that although it might be possible mechanically to read the times with this accuracy, the result would be entirely illusory. Hence the times have been recorded to the nearest tenth-minute only.

MICROSEISMS.

In addition to the true earthquakes, and the local disturbances caused by street traffic, railway trains, etc., the seismograph records a peculiar species of very small vibrations known as "pulsatory oscillations," "microseismic unrest," or briefly "microseisms." The term microseisms will thus be understood to include all pulsatory disturbances not directly traceable to what are ordinarily known as earthquakes, and to local disturbances due to traffic, etc.

The microseisms appear on the seismogram as small amplitude vibrations of regular or irregular period, continuing without interruption for hours, and frequently for days. Many prominent seismologists have studied these disturbances with some care, but without being able to arrive at any really satisfactory explanation of the cause of the phenomenon. It has been found at this, as at other stations, that local winds, temperature changes, and pressure gradients appear to be without direct effect in producing these disturbances. It has been observed here as well as elsewhere that the microseisms are more frequently seen in the winter season than in the summer.

At this observatory the record of microseisms is somewhat embarrassed by the tremors and disturbances produced by passing railway trains. Although in general the record of passing trains is simply a thickening of the line traced by the recording point, produced by very short period vibrations of very small amplitude, lasting from 0.5 to 2 minutes, there will be frequently produced vibrations of longer period and larger amplitude closely resembling microseisms. This effect has generally been noticed when the microseisms are of small intensity, and one receives the impression that the surface of the ground is in such a condition of equlibrium that the least impulse will cause it to commence vibrating. At such times the train disturbances can easily be mistaken for microseisms.

Klotz has found that the microseisms observed at Ottawa are accompanied by the presence of a low pressure area over the Gulf of St. Lawrence and surrounded by fairly steep gradients; with increased intensity of the microseisms if there is at the same time a high pressure area on the Atlantic coast north of Florida.

Wiechert and Linke, the latter from observations made at Apia in the Pacific ocean, have concluded that in the microseisms we have to do with the oscillations set up by the pounding of the surf on the shore of the ocean. While this may be true regarding microseisms observed at Apia, it will hardly be believed that the ocean surf can have an effect in any way appreciable at Ann Arbor, which is situated more than 850 km from the nearest sea coast.

Following out Klotz' hypothesis a comparison was made between the weather maps and the dates on which microseisms had been observed at Ann Arbor. There is some evidence of correlation between the prevalence of lows over the Gulf of St. Lawrence and the microseisms at Ann Arbor. That is, during months when lows over the Gulf are numerous, microseisms will be found frequent at Ann Arbor. However there are occasions when strong microseisms were recorded here during the absence of a low over the Gulf. Similarly lows were found over the Gulf when no microseisms were recorded. The period during which observations have been made is rather short, and comparisons should be extended over a longer period before a definite conclusion can be reached.

The microseisms recorded at this observatory seem to be somewhat sharply divided into two classes. The regular or usual type with period

of vibration 7-8 seconds, and those with irregular period.

The microseisms of the regular type are the more numerous. They commence gradually, with the appearance of scattered groups of vibrations of small amplitude (Fig. 1, Plate XIII). This group arrangement of the vibrations is quite characteristic of the regular microseisms. The amplitude of the vibration increases, reaches a maximum and then diminishes, the whole lasting about a minute; the groups recurring more or less regularly at intervals of two or three minutes. The appearance seems to indicate either that it is an interference effect, or that the disturbing force acts in a series of impulses of about equal intensity but of slightly irregular period. After the maximum amplitude has been reached (usually about 0.5 mm), the microseisms may continue for a few hours or for one or more days, sometimes maintaining a constant intensity, sometimes decreasing for a while and then increasing again. The ending of the period is usually the reverse of the beginning, the tremors becoming less numerous, with smaller amplitudes until they finally cease altogether. (Fig 2, Plate XIII). So far the sudden beginning or ending of a period of microseisms has not been observed.

The grouping effect is conspicuous on the Wiechert records. The groups are more sharply defined than on the Bosch records, that is, the recording point comes to a period of absolute rest between the groups of microseisms, while the beginning and ending of each group is quite abrupt. This is doubtless a damping effect. It is rather curious that the vibrations in these groups on the Wiechert record are sometimes decidedly irregular, and at other times are quite regular. The Bosch record is however the same at both times, and nothing can be learned from it regarding the kind of "regular" microseisms that will be found on the Wiechert record.

The irregular microseisms occur less frequently than the regular. They show nothing of the group arrangement, but consist simply of continuous vibrations of irregular period and unequal amplitude (Fig. 3, and 4, plate XIII). Similar to the regular microseisms just described, they commence and end gradually. Rather strangely microseisms of this class are rarely recorded by the Wiechert instruments; even when very strong movement has been recorded on the Bosch records, there is not the least trace of this on the Wiechert record. For recording microseisms the Bosch instruments at this observatory are decidedly superior to the Wiechert.

Apparently there are two causes at work producing these two classes of tremors. On several occasions, particularly November 20-21, 29-30, 1911, the records show the irregular microseisms decreasing in intensity, while simultaneously the regular microseisms begin, with the appearance of occasional groups of tremors interspaced among the irregular vibrations. The groups gradually become more numerous, while the irregular microseisms diminish in intensity and finally disappear.

In the list given below, are noted data concerning the microseisms recorded by the seismographs at this observatory. As has been noted before, all times given are Central Standard Time, midnight to midnight. The seismograph sheets are renewed daily at about 8 hrs. (8 a. m.), hence the "seismograph day" can be considered as beginning at this time.

RECORD OF MICROSEISMS.

1909.

Sept. 8-9.
Microseisms of moderate intensity recorded on B — E W. Period of vibration about 8 sec., amplitude 0.5 mm.

Sept. 9-10.
Microseisms similar to above but less numerous. Traces of these are shown on the B — N S record.

Sept. 12-13.
Microseisms similar, but not recorded on B — N S.

Sept. 13-19.
Similar microseisms recorded during all this period on B — E W, and occasionally on B — N S. These are generally of short period and small amplitude.

Sept. 20-22.
Numerous microseisms during this period recorded in B — E W. Small amplitude.

Sept. 24-26.
Similar to above, with occasional traces of movement on B — N S.

Oct. 5-10.
Numerous microseisms during this period, very small amplitude. Traces of movement on B — N S.

Fig 1

Fig. 2

Fig. 3

Fig. 4

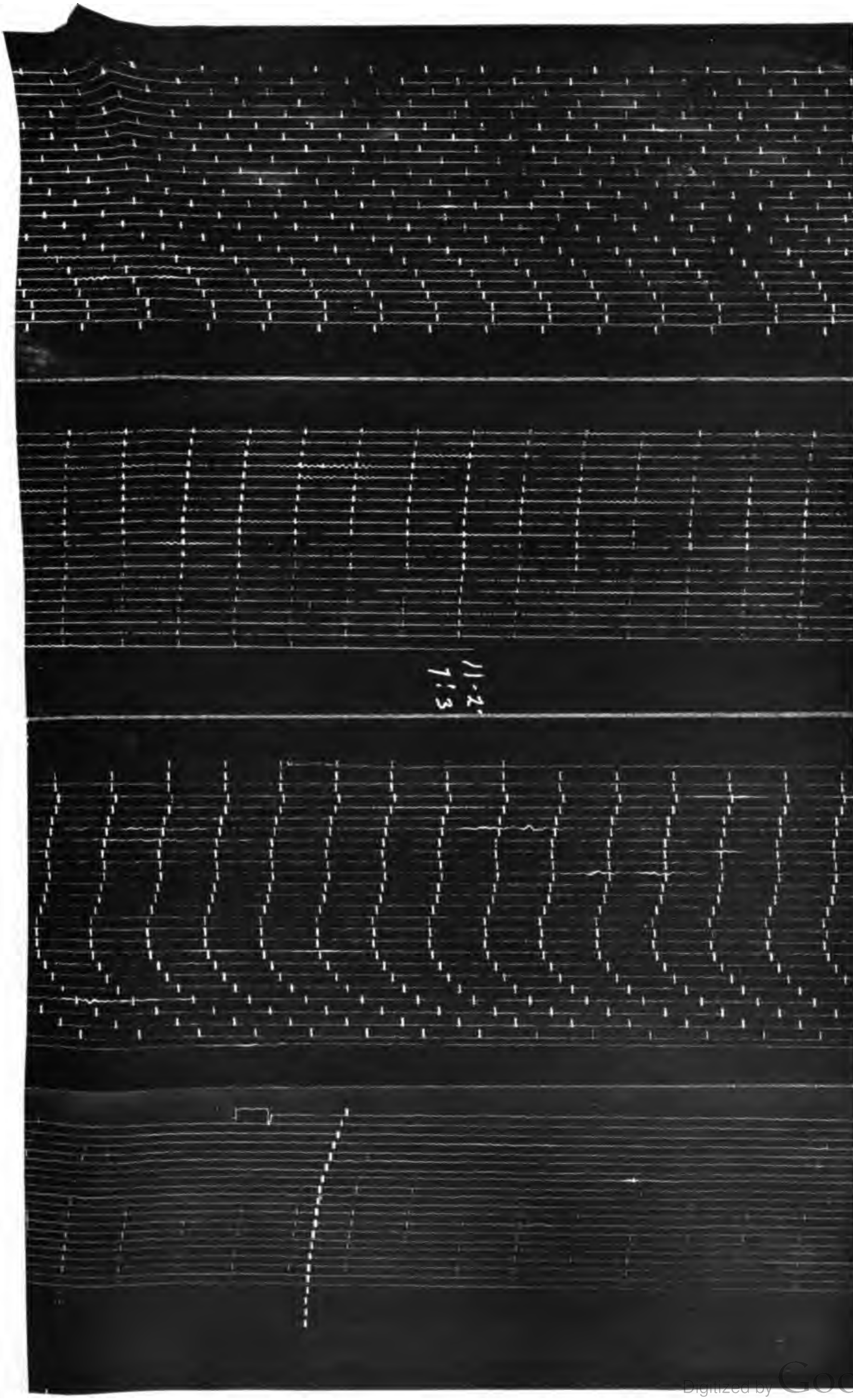

PLATE XIII.

FIG. 1. B—EW. JANUARY 20-21, 1911.

FIG. 2. B—NS. NOVEMBER 26-27, 1911.

FIG. 3. B—EW. DECEMBER 27-28, 1911.

FIG. 4. B—NS. NOVEMBER 12-13, 1911.

Oct. 12-13.
Both B — E W and B — N S records show irregular wave-like motion. This is practically continuous during the day, and of longer period than the regular microseisms. High winds.

Oct. 15-16.
Both Bosch components show numerous microseisms of small amplitude.

Oct. 22-23.
Occasional microseisms on both Bosch records.

Oct. 26-29.
Microseisms of small amplitude are almost continuous during the day. Distinct traces on W — N S record.

Nov. 6-7.
Microseisms continuous during this period. Intensity nearly equal on Bosch records, but stronger in W — N S than W — E W, small amplitude.

Nov. 10-11.
Microseisms during second half of this period. These are quite pronounced, and stronger on B—EW than B—NS. Show only very slightly on Wiechert records, in contrast to preceding period.

Nov. 11-12.
Microseisms continue, but gradually die out by the end of this period.

Nov. 24-25.
Microseisms of considerable amplitude. More conspicuous on B — E W than B — N S. Conspicuous on W — N S, with traces on W —E W.

Dec. 5-6.
Continuous tremors during the day. These are of irregular period and small amplitude, although some are as great as 0.5 mm. These tremors are particularly noticeable on the B — NS record. Only very faint traces on Wiechert records. Tremors gradually subside during A. M. of the 6th.

Dec. 7-8.
Tremors similar to above beginning about 15 hrs on the 7th, and continuing through the next day.

Dec. 8-9.
Tremors continued from the day before. These have become very prenounced. Amplitude as great as 0.5 mm, period very irregular. These vibrations in no way resemble the ordinary microseisms, being much more irregular, and continuing for hours at a time. Maximum disturbance seems to be at about 18 hrs on the 8th. Slightly more conspicuous on the B — N S record than on the E W component. Tremors seem to be absent from W — E W record, only the faintest traces on W — N S.

Dec. 9-10.
Tremors continued. Probably a small shock beginning 9 da 10 hrs 32 m continuing until 11 hrs 3 m. This is simply a series of waves of 0.5 mm amplitude, and about 15 sec. period. Not shown on B—NS, but is conspicuous on B—E W and shows distinctly on both Wiechert records.

Dec. 10-11.
Continuation of these tremors, but gradually diminishing in intensity.

Dec. 12-13.
Microseisms of the usual type, amplitude very small. Faint traces on the Wiechert records.

Dec. 17-19.
Microseisms of small amplitude recorded on both Bosch records. The period on N S record is distinctly longer than on EW; may be due to interference with the pendulum swing.

Dec. 19-20.
Microseisms of small amplitude during this period. More conspicuous on B — N S than B — E W. (This is unusual). Not visible on Wiechert records.

Dec. 26-27.
Conspicuous microseisms on both Bosch records. Slight traces on Wiechert records.

Dec. 28-31.
Strong microseisms during the beginning of this period; these gradually diminish in intensity. Visible on both Wiechert records.

1910.

Jan. 1.
Strong microseisms, very conspicuous on the B—EW record. Traces on both Wiechert records. These microseisms preceded the earthquake elsewhere recorded.

Jan. 1-3.
Very slight traces of microseisms after yesterday's shock, becoming stronger on the 3rd. These are more prominent on the B — E W and W — N S records.

Jan. 10-13.
Slight traces of microseisms on Bosch records.

Jan. 25.
Small disturbance at 16 hrs 10 min, lasting 1.8 min. This is recorded on both Wiechert sheets but not at all on Bosch records, and may be due to the presence of visitors in the seismograph room.

Jan. 27-30.
Slight traces of microseisms during this period.

Feb. 9-10.
Microseisms during this period. More conspicuous on the B — E W, and W — N S records. Faint traces have been visible for several days previous to this.

Mar. 11-12.
Microseisms of considerable intensity during this period. These are conspicuous on the W — N S record, but are absent from the W — E W. E W component is the more prominent on the Bosch records.

Apr. 3-4.
Occasional tremors of small intensity.

Apr. 15-16.
Similar to above.

May. 11-12.
Slight tremors on the Bosch records beginning 12 da 3 hrs 10 min and continuing until 3 hrs 26 min. Traces of these on Wiechert record.

Jun. 15-16.
Slight microseisms on both E W records preceding shock of this date.

Jun. 16-17.
Microseisms of small intensity frequent during this period.

July 17-18.
Occasional microseisms of small intensity during this period.

Aug. 25-27.
Similar to above. Some of these tremors may be caused by passing traffic, as the train disturbances are unusually prominent.

Sept. 18-20.
Mcroseisms of small amplitude which become more numerous towards the end of this period.

Oct. 3-4.
Traces of microseisms on all records, very small amplitude.

Oct. 11-14.
Microseisms during this period. These begin with small amplitude, growing stronger and reaching a maximum on the 13th, then diminishing. These tremors are conspicuous on both Bosch records, but only faint traces on the Wiechert records.

Oct. 14-17.
Occasional microseisms of small amplitude on Bosch records.

Oct. 18-22.
Microseisms of moderate amplitude on Bosch records, faint traces of these on the Wiechert records.

Oct. 24-25.
Strong microseisms beginning on the 25th. Conspicuous on both Bosch and W — N S records, faint traces on the W — E W record.

Oct. 25- 27.
Strong microseisms continued, intensity beginning to decrease. None recorded after the morning of the 27th.

Oct. 27-28.
Strong microseisms again, beginning on the 27th. Conspicuous on the Bosch and W — N S records.

Nov. 9-12.
Occasional microseisms during the early part of this period, becoming stronger on the 12th. Recorded with both Bosch, and W — N S.

Nov. 16-19.
Occasional microseisms during this period.

Nov. 23-24.
Occasional microseisms of moderate intensity on the Bosch records. These are very conspicuous on the W—EW record (rare), and much resemble a succession of small shocks during the day.

Nov. 24-25.
Similar to above.

Nov. 26-27.
Microseisms conspicuous on the Wiechert records. These are quite irregular and in no way similar to those usually recorded on the Bosch sheets.

Nov. 27-28.
Similar to above, but with decreasing intensity.

Nov. 28-29.
Traces of microseisms on the Bosch records. These are conspicuous on the W — E W record. Traces on W — N S.

Nov. 30-1.
Conspicuous microseisms on Weichert records, of moderate intensity on Bosch records.

Dec. 1-5.
Microseisms of moderate amplitude during this period on Bosch records. These are occasionally conspicuous on the W — E W record, and are much more irregular than on the Bosch. This may be an instrumental effect.

Dec. 7-8.
Tremors have been continuous until this date. The character now changes, the Bosch records showing irregular tremors during the day. This is especially prominent on the E W record, the tremors being very irregular and continuous. This is practically duplicated on the Wiechert sheet.

Dec. 8-10.
Similar to above, with a small shock early on the morning of the 10th.

Dec. 12-13.
Irregular tremors have continued up to this time. The character now changes, becoming more regular.

Dec. 16-17.
Microseisms beginning during the latter portion of this period.

Dec. 17-19.
Strong microseisms during the early portion of this period, these gradually disappearing during the 19th. These tremors are of the usual or "regular" type more prominent on the Bosch than on the Wiechert records. This would seem to indicate that tht Wiechert instrument is more sensitive to irregular tremors than is the Bosch, but the effect may be produced through interference on account of the periods of the pendulums.

1911.

Jan. 4-5.
Continuous irregular tremors during this period, becoming stronger during the latter portion. These are conspicuous on Bosch records but are not seen on the Wiechert sheets. This is the opposite of what has just been noted above.

Jan. 8-9.
Strong irregular tremors during the middle portion of this period. These are conspicuous on the B—EW and W—EW records with traces on the NS records.

Jan. 17-18.
Faint traces of the regular microseisms.

Jan. 20-21.
Strong irregular tremors beginning during the evening of the 20th. These are very conspicuous on the Bosch and W — E W records, traces on the W — N S record.

Jan. 21-22.
Tremors continued, but disappearing by the evening of the 21st.

Feb. 19-20.
Traces of short period regular microseisms on the Bosch records.

March 4-5.
Short period microseisms of small amplitude on Bosch records, traces of these on the Wiechert records.

April 20-22.
Short period, regular microseisms of small amplitude on Bosch records; only the faintest traces of these with Wiechert. Gradually disappearing during the 22nd.

July 3-4.
Beginning 4 da 7 hrs 46 min is a series of tremors, possibly a small shock, amplitude very small; this continues for about an hour. Recorded on both Bosch sheets but not on Wiechert.

July 24-25.
Slight irregular tremors on the B — N S record, but not recorded elsewhere.

Aug. 21-22.
Beginning at 10 hrs 54.3 min on the 21st., a series of tremors lasting about 17 min, possibly a small shock. Seen on both components of Bosch records, but absent from Wiechert.

Sept. 7-8.
Slight traces of microseisms on both Bosch records.

Sept. 8-9.
Microseisms continued, slightly stronger. Faint traces on the Wiechert records.

Oct. 2-5.
Strong microseisms, continuous and more conspicuous on the NS components of both sets of instruments than on the EW. These tremors gradually disappear during the 5th.

Oct. 13-14.
Microseisms beginning, become strong at the end of this period on all records but the W — E W.

Oct. 14-16.
Strong microseisms continued; disappearing during the 6th. Tremors are regular with small period, except from 11 hrs 10 min to 11 hrs 20 min on the 14th, during which time they are irregular and with longer period.

Oct. 23-24.
Long period tremors (15—20 sec.), with very small amplitude. The record has the appearance of a slightly wavy line. This is conspicuous on the B — N S record. Tremors not shown on Wiechert records.

Nov. 2-3.
Irregular tremors of long period and small amplitude, prominent on the B — N S record only.

Nov. 8-9.
Regular microseisms beginning during the latter part of this period. These are more prominent on B — E W than on B — N S record. Not visible on Wiechert records.

Nov. 9-10.
Microseisms continued, but disappearing toward the end of this period.

Nov. 11-12.
Strong irregular tremors beginning about 6 hrs on the 12th. These are nearly continuous, occasionally interrupted by short period vibrations. Amplitude frequently 0.5 mm. These tremors are conspicuous on both Bosch records, but only the faintest traces on the W — N S.

Nov. 12-13.
Tremors continue. B — N S record is the stronger. Not visible on Wiechert records.

Nov. 13-15.
Tremors continue, but with diminished intensity.

Nov. 17-18.
Continuous irregular tremors. These are stronger on B — E W record. Not visible on Wiechert records.

Nov. 18-19.
Very strong irregular tremors continuous during this period. These are stronger on B — E W record. Amplitude frequently over 1 mm. Wiechert record is incomplete, but there are no traces of these tremors.

Nov. 19-20.
Tremors continue, but with diminished intensity.

Nov. 20-21.
Tremors continue, but short period microseisms of the regular type are numerous and interspaced with the irregular tremors. This is of particular interest; the short period microseisms are beginning while the irregular tremors are dying out. Evidently there are two different causes at work.

Nov. 25-26.
Regular short period microseisms developing during this period and becoming very strong at the end. Very conspicuous on both Bosch records, but only faint traces on W — N S.

Nov. 26-27.
Very strong regular microseisms of short period on both Bosch records, gradually dying out on the 27th. Visible on W — E W record.

Nov. 29-30.
Irregular microseisms beginning at the end of this period, interspaced with the short period regular type. Conspicuous on both Bosch records, but no traces on the Wiechert.

Nov. 30—Dec. 1.
Irregular tremors continued, gradually disappearing.

Dec. 21-22.
A series of irregular tremors beginning 21 da 7 hrs 6 min and continuing until sheets were changed, about 24 min. This was probably a small shock, amplitude over 1 mm. On both Bosch records, but only on W — E W.

Dec. 23.
A series of irregular tremors beginning 14 hrs 1 min and continuing for two minutes, gradually dying out. This is conspicuous on W — N S but absent from W — E W. This is probably a small shock. Another follows an hour later, see elsewhere.

Dec. 24-25.
Small irregular tremors on Bosch records. Traces of these on W — N S.

Dec. 25-26.
Small irregular tremors. Not on Wiechert records.

Dec. 26-28.
Beginning 0 hrs on the 27th, strong irregular tremors commence and become stronger. More conspicuous on the B — E W record, with only faint traces on W — N S. These tremors gradually disappear by 17 hrs on the 28th.

Dec. 29-30.
Slight irregular tremors on B — E W record.

Dec. 30-31.
Continuous irregular tremors of moderate intensity on B — E W record.

Dec. 31—Jan. 1.
Very strong continuous irregular tremors. Amplitude greater than 1 mm. Very conspicuous on B — E W record, only faint traces on W — N S. These irregular tremors continue in an almost unbroken succession during the month of January. A detailed account of these will be given in a subsequent publication.

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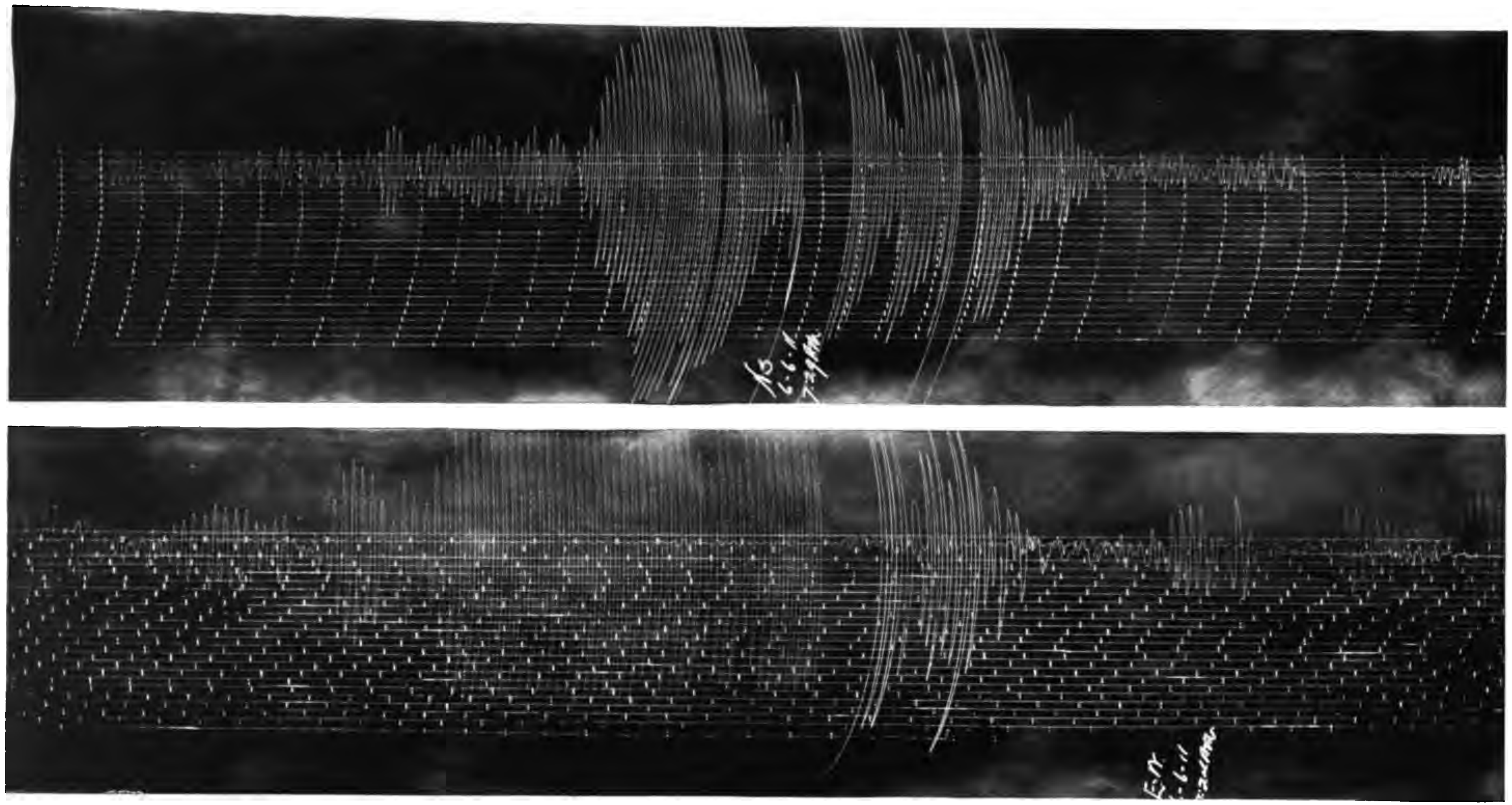

PLATE XIV. DETROIT OBSERVATORY SEISMOGRAM OF THE GREAT MEXICAN EARTHQUAKE OF JUNE 7, 1911, RECORDED BY THE BOSCH-OMORI HORIZONTAL SEISMOGRAPHS.

MISCELLANEOUS OBSERVATORY NOTES.

By W. J. HUSSEY AND R. H. CURTISS

INTRODUCTORY.

A general description of the Observatory and its equipment is given in the first part of this volume. The following paragraphs may be regarded as a continuation of that account, designed to indicate the more important additions and improvements which have been made since it was written and to give notice of the principal investigations now in progress.

THE REFLECTING TELESCOPE.

The large reflecting telescope was completed in May, 1911, and since that date it has been used on nearly all favorable nights for photographing stellar spectra. The principal series of observations, for which more than 3200 spectrograms have already been secured, are indicated below. For spectroscopic work, for which it was designed, the efficiency of the telescope has exceeded expectations. Working with an equivalent focal length of sixty feet and with a single-prism spectrograph having a dispersion of 40.3 Angstroms per millimeter at $H\gamma$, satisfactory spectrograms are obtained with exposures of six hours of stars of the 10.5 photographic magnitude, with accompanying comparison spectra. The spectra of solar type stars extend from about λ 4000 to λ 5000, and they are therefore about an inch in length. They are sharp in definition, and although usually measured under a magnification of from 12 to 15 diameters, they will if required stand somewhat higher powers up to about 20 diameters, a limit set ordinarily by the size of the silver grains in the film.

With the ability to carry spectroscopic investigations to stars of the 10.5 photographic magnitude, which is nearly two magnitudes beyond that anticipated, there is practically an unlimited amount of work available for this instrument.

The degree of efficiency which now obtains in the use of this telescope and spectroscope has been reached by a careful attention to details, and to the removal, as far as practicable, of those imperfections which existed in the apparatus when it was first installed. In the beginning the telescope and spectroscope performed excellently, but various modifications suggested by experience have been made, and through successive corrections better adjustments have been secured, rendering the instrument more easily manageable and more efficient.

NEW PRISM FOR THE SPECTROGRAPH.

The first prism which was selected for the single-prism spectrograph of this Observatory was made of Jena glass, O:102. This particular material was selected because of the stamp of approval which had been placed upon it through its prolonged use in several spectrographs, and because of the difficulties which were encountered at the Yerkes Observatory in the attempt to employ prism glass of lower density. However, when stellar spectrograms were made with our prism of this material, it was recognized at once that an excessive prismatic loss of light was taking place, especially in the important spectral region about λ 3900. Accordingly, on November 6, 1912, a new prism of Jena ordinary flint glass, similar to No. 313, was ordered from the J. A. Brashear Company, and on May 20, 1914, when our programs permitted, it was substituted for the old dispersion piece. As a result, the loss of light in our spectrograph was appreciably reduced, especially in the K region. At the same time the dispersion was reduced about five per cent. The definition and extent of field in good focus remained as before. Velocities determined with the new prism are certainly as good as those obtained with the old, while the advantage of greater transparency is an important one.

The maker's indices of refraction for the glass of the new prism are as follows: 1.6209 for λ 6563.1, 1.6259 for λ 5893.2, 1.6384 for λ 4861.5, and 1.6491 for λ 4308.0. The refracting angle of the new prism is 64° 40′; length of face, 3.18 inches; length of base, 3.40 inches; and height of prism, 1.70 inches. The deviation at the $H\gamma$

line is 59°. The dispersion for the same line is 40.3 Angstroms per millimeter, whereas for the old prism it is 37.9 Angstroms per millimeter.

A DEVICE TO COMPENSATE FOR ATMOSPHERIC DISPERSION.

Spectrographic observers who have worked with large reflectors are well aware that the image of a star at considerable zenith distances is a spectrum, only one color of which may be introduced centrally into the spectrograph slit at one time, unless it happens momentarily to lie along a vertical circle. If the guiding be done on a certain color the centers of the images of the star in other colors will in general be continually on one side or the other of the slit. Thus, only part of the light in these other colors will enter the slit, and on this account the extent of the spectrum photographed may be greatly limited. At the same time, since the star image in such other colors will be kept systematically off center with the slit, radial velocities determined from lines in regions of the spectrum corresponding to these colors may be adversely affected. Unfortunately these difficulties are especially great in the case of photographic light, which the spectroscopic observer is especially desirous of getting, and obviously the low dispersion spectrograph is more especially affected.

In order to eliminate this difficulty due to atmospheric absorption, a simple device has been tried at this Observatory by Dr. R. H. Curtiss. This device consists of a small plane parallel plate of light flint glass mounted immediately in front of the spectrograph slit in such a manner that it may be tipped at will in any direction. It is well known that a ray of white light after passage through a plane parallel glass plate at an angle emerges parallel to its original direction but with the several colors relatively displaced by amounts depending upon the angle of incidence, the optical constants of the glass, and the thickness of the plate. Conversely, if such rays of the several displaced colors be passed through such a plate at the proper angle they will be united again into a single white ray.

Similarly, the several essentially parallel beams, corresponding to the star images, relatively displaced by atmospheric dispersion, may be brought into close coincidence and thus may be united on the slit by the interposition before the slit of a plane parallel plate of suitable constants, tipped about an axis making a right angle with the vertical.

The parallelopiped used successfully to compensate for atmospheric dispersion in connection with our large reflecting telescope is of ordinary flint glass, O:103, with an index of refraction of 1.649 at λ 4300. The dimensions of the face upon which the starlight is incident are two by one and a quarter inches, and the thickness is three-fourths of an inch.

The small disturbance of the identity of source, occurring in connection with the use of this device, is not a consideration, but the light lost, chiefly by reflection at the surfaces of the plane parallel plate, amounts to about twenty per cent. Accordingly, it will require some experiment to determine the circumstances under which the advantages attending the use of this device will outweigh the disadvantage resulting from the loss of light.

IMPROVEMENTS IN THE DRIVING MECHANISM OF THE LARGE REFLECTOR.

When the 37½-inch reflector was assembled, in 1911, the various elements of the driving mechanism were set up substantially as they came from the instrument shop, without lapping, or great care in alignment and adjustment. This, of course, was done intentionally, since it was known that the accuracy of the driving under these circumstances would, for a limited time at least, be sufficient for spectrographic work.

Tests of the apparent motion of the star image on the spectrograph slit brought out many minor irregularities, a long period combination of short period terms, and, far in excess of all other periodic variations, a four-minute oscillation with a double amplitude, on the average, of about three and a half times the length of the spectrograph slit. The observation of this large oscillation, having the same period as the worm shaft, enabled us to localize the chief difficulty at once, but it was decided that all parts of the driving train should be gone over carefully and placed in the best condition possible.

Two pairs of very accurate bevel gears were

obtained from The Brown & Sharpe Company, for use between the driving clock and the worm shaft. These replaced two pairs of smaller gears which had been cut on our milling machine. The new gears, as well as the worm and worm wheel, were lapped for many hours with suitable abrasive. The shaft leading from the driving clock to the worm shaft was carefully aligned and was provided with an additional supporting bearing near its upper end. A new worm shaft was made. The four differential gears of the slow motion in hour angle were eliminated from the clock train by the simple expedient of removing the brake which forced them to revolve. The governor system was tested and made as efficient as possible. And subsequently an electric control on the governor shaft was introduced to be used for guiding of high accuracy.

These various expedients reduced greatly the minor irregularities but left the amplitude of the four minute oscillation substantially as before. Simple considerations made clear that the cause of this oscillation did not lie in the bevel gear on the worm shaft, but that it was to be found either in a periodic error in the worm or worm wheel, or in an eccentricity in the mounting of the worm. In either case it was clear that a very small *decentering* of the worm on the worm shaft would correct the difficulty with very little expenditure of time. Accordingly, the worm shaft, upon which the worm had been an accurate fit, was turned down 0.014 inches, and the bearing of the worm upon the worm shaft was restricted to two sets of opposing screws at each end of the worm. By altering these screws the worm was *decentered* a very small amount, by the method of trial and error, until the star image remained for a long period on the slit and no movement which was certainly periodic was observed. The decentering of the worm had no observable effect upon its operation aside from the accomplishment of the desired end of eliminating its periodic error. By these alterations and adjustments the driving facilities of this instrument have been made eminently satisfactory.

NEW DECLINATION SETTING CIRCLE.

When the large reflector was installed, a setting scale for hour angles was placed on the south face of the north pier, near the quick motion handles. It is within a few feet of the observer when he is making a pointing of the telescope. It has been found convenient to have an equally accessible means of setting in declination, in addition to the usual circle on the telescope. To this end a dial, three feet in diameter, made of wood and brass, has been mounted to rotate on a central pivot immediately above the declination fast motion handle. This dial, which is graduated in degrees, is in effect a large spur gear with teeth in mesh with a small spur gear on the handle shaft of the declination fast motion. To allow for back lash in the fast motion train two indices suitably placed are used for setting or reading the dial.

ELECTRIC SLOW MOTION IN DECLINATION.

An electric slow motion in declination, controlled by a switch at the eye end of the instrument, has been added to the large reflector. A motor of one-eighth horse power is used. It operates, through a differential gear, upon the large screw at the end of the slow motion sector.

A PHOTOMETRIC PLATE HOLDER FOR THE LARGE REFLECTOR.

A photometric plate holder, for use inside the Cassegrain focus of the 37½-inch Reflector, has been designed by Dr. R. H. Curtiss, and constructed in the Observatory Shop by Mr. E. J. Colliau. The plate holder is carried by a double slide, operated by racks and pinions, making possible the photography of a large number of intra-focal images, side by side. A convenient screw motion permits accurate adjustment of the distance from focus. A finding and centering telescope is also provided. An electrical shutter makes convenient the necessary accurately timed exposures. The whole apparatus is mounted, without interference, between the spectrograph and the back of the mirror cell.

A COMPARATOR FOR STAR PHOTOGRAPHS AND SPECTROGRAMS.

A large comparator, for the measurement of rectangular and polar co-ordinates, has been designed by Dr. R. H. Curtiss, and constructed in

the Observatory Shop by Messrs. H. J. and E. J. Colliau. It is similar in principle and scope to the standard Gaertner comparator, described and illustrated on page 23 of Gaertner's Catalogue A, of 1908, and there designated as A 1203. The instrument made here is considerably larger than the Gaertner model, and will measure 120 mm. in either co-ordinate. The base resembles that of the Hartman Spectrocomparator, and the microscope is supported by lateral arms. The accurate screws are each of one millimeter pitch, and may be used with heads to read microns, or with larger heads which read to half microns.

Probably the most interesting innovation in the construction of this comparator is the use of steel balls as a substitute for the main guiding ways, for carrying most of the weight of the moving parts. This relieves the horizontal screw of much of its work in moving the carriage, and reduces wear and strain. The balls, although not held apart by springs, give no trouble by massing too closely.

This comparator has been used extensively as a measuring engine for stellar spectrograms. In this connection the horizontal screw has been tested on several occasions and has been found after much use to retain its original satisfactory accuracy. For work on spectrograms a third slide is mounted on the position angle circle. This slide carries the spectrogram. It is moved by hand and is easily reversed. This instrument, though unnecessarily large for the purpose, has been found very useful and convenient for the measurement of spectrograms.

A SECOND MEASURING ENGINE FOR SPECTROGRAMS.

A close duplicate of Measuring Engine, No. 1, shown on page 52 of this volume, has been constructed by Mr. E. J. Colliau, in the Observatory Shop. The graduated head of the screw of this new engine is mounted between opposing screws, to permit decentering the head, for the elimination of possible periodic errors in the accurate screw which moves the plate carriage. However, the screw and nut which Mr. Colliau has made for this engine are so accurate that this adjustment has not been necessary.

The accurate screws of all our measuring engines are supported in a line bearing near the graduated head, and in the moving nut. The lower end of the screw of each engine is hardened and ground to a point, which bears upon a hardened and ground surface, this contact being ensured by the tension of a coiled spring, mounted at the end of the engine bed.

A HARTMANN MICROPHOTOMETER.

A Hartmann microphotometer, by Otto Toepfer and Son, for the photographic measurement of surface brightnesses, has recently been received. The instrument, as ordered, is Model 25, provided with a large round table, on which the object observed is moved about by hand under the microscope. Two Lummer-Brodhun prisms are used with the instrument, the one with a circular reflecting surface, and the other with a narrow vertical reflecting strip. An auxiliary apparatus for the preparation of photographic wedges was also obtained with the instrument.

As contemplated at the time of purchase, a triple slide plate support has been made in the Observatory Shop, to replace the round table referred to above. This was designed by Dr. R. H. Curtiss and constructed by Mr. E. J. Colliau. Two of the triple slides in this new attachment provided right and left motions for the object under the microscope, a quick hand motion, and, for accurate measures, a slow screw motion with a large graduated head. The third slide, which is operated by a rack and pinion, provides a vertical motion of the image in the microscope field. The plate carriage accommodates plates 3¼ by 4¼ inches and smaller.

The accurate screw of this triple slide plate carriage, which indeed may be used as a measuring engine if desired, is mounted in a novel manner. Near its graduated head, the screw is supported by a ball and socket joint, which has been made and lapped very carefully. The second support of the screw is the moving nut, which however serves only as a guide, since the weight of the screw balances at the ball and socket support. The lower end of the screw is free and without bearing, and the usual tension to take up back lash is supplied by a coiled clock spring. The advantage of this form of screw mounting over that in use in other engines at this Observatory is found in a reduction of the

chances of accident to the screw. This screw has been tested and has been found to possess the high order of accuracy which characterizes all the engine screws which have been made in the Observatory Shop.

PROGRAMS WITH THE LARGE REFLECTING TELESCOPE.

Work was begun with the 37½-inch Reflecting Telescope on May 19, 1911, and since that time it has been employed almost exclusively for photographing stellar spectra by means of the single prism spectrograph, described in the earlier part of this volume. More than 3200 spectrograms have been secured, distributed among the following programs:

1. *Stars of Class B, with Bright Lines.*—This program was begun on May 24, 1911, by Dr. R. H. Curtiss. To the present nearly all of the stars of this class, brighter than the fifth magnitude, have been observed, and in some cases extensive sets have been secured. The observations are being extended to fainter stars.

2. *The Early Potsdam Velocity Stars, not known to be Binaries.*—This program has been carried to completion. The observations have been made for the most part by Mr. L. L. Mellor.

3. *Long Period Variables.*—This program, now well under way, has been carried on exclusively by Dr. P. W. Merrill.

4. *Zone Stars to the Sixth Visual Magnitude, between 35° and 40° of North Declination.*—Charts and other data have been prepared for this program and a beginning has been made on the observations.

5. *Stars of Class R.*—The spectra of ten stars of Class R are being investigated by Mr. W. C. Rufus. In the course of this work several spectrograms of stars of photographic magnitude about 10.5 have been made. This program is nearing completion.

6. *Spectroscopic Binaries, Established and Suspected.*—The list of these objects, arranged in an order indicating the progress of our observations, is here given: Delta Orionis, Epsilon Orionis, 20 Tauri, the components of Zeta Ursae Majoris, Beta Cephei, Beta Lyrae, Gamma Lyrae, Gamma Cassiopeiae, Rho Leonis, R Scuti, Beta Librae, Alpha Ophiuchi, g Ursae Majoris, Alpha Cygni, 12 Canis Venaticorum, and scattering plates of other binaries. In making the plates of this program the Observatory staff has been assisted materially by Dr. G. A. Lindsay, Professor Laurence Hadley, Mr. C. C. C. Crump, and Professor G. W. Hess.

7. *Miscellaneous Objects.*—The miscellaneous objects of which spectrograms have been made include the following: Nova Geminorum No. 2, Comet Delavan, 1913 *f*, the components of Beta Cygni, several Pleiades stars, several Class N and Class O stars, the Trapezium stars, Saturn, the moon, and the sky.

THE HOWELL TELESCOPE.

The Honorable J. E. Howell, Vice Chancellor of the Court of Chancery of the State of New Jersey, a graduate of the Law Department of this University, has recently presented the Observatory a portable telescope from his private Observatory.

This telescope has a clear aperture of 4.6 inches and a focal length of about six feet. It is equatorially mounted, on a tripod, and adjustable to any latitude. The tube is of brass, highly polished, and lacquered. It is provided with a finder having an aperture of 1.3 inches, hour and declination circles, clamps, and worm gears for giving the telescope slow motions in right ascension and declination. There are six eye pieces, having powers ranging from 64 to 320 diameters.

The instrument was made by Benj. Pike's Son, New York, and has recently been put in excellent condition by Gall & Lembe. While in the possession of Judge Howell, the objective was refigured by John Byrne.

THE LAMONT REFRACTOR.

Mr. R. P. Lamont, of Chicago, has provided the funds for constructing a 24-inch refracting telescope for this Observatory. The completion of this instrument is being delayed, owing to the difficulty of producing the glass required for the objective. It was ordered in February, 1911, and although four years have now elapsed, the glass has not yet been received by the opticians. The latest report of the glass makers, at Jena, Germany, stated that the crown disk had been made, and that they had also produced a mass of flint

glass sufficiently large for the flint disk. This will have to be formed into a disk and then pass through the final annealing and testing processes, which will probably require several months. Were it not for the abnormal conditions in Europe, owing to the war, we should expect the delivery of the disks during the present year.

The mounting for this telescope is being made in the Observatory Shop and is now in an advanced stage of construction. The driving clock, clock-room section of the pier, polar head, all mechanism connected with the polar and declination axes, the lower section of the tube, drawtube, clamps, and slow motions have been completed and assembled. The work upon the instrument has proceeded as far as is practicable until the focal length of the objective has been determined, and this must await the decision of the opticians after their examination of the glass.

THE WORK AT LA PLATA.

In carrying out its part of the agreement with the University of La Plata, the University of Michigan has, from time to time, since 1911, granted leaves of absence to Professor Hussey to enable him to organize and direct the work of the La Plata Observatory. He has now spent three periods in Argentina, aggregating five semesters, during which the principal instruments have been put in order and the following programs of observational work undertaken.

The 17-inch refractor has been used regularly for the discovery and measurement of double stars and for the observation of comets and minor planets. This work has been done principally by Professor Hussey and Mr. B. H. Dawson.

In the past much of the double star work in the southern hemisphere has been of a fragmentary character and lately there has been an insistent need of more observations. The work in this department at La Plata was undertaken with the idea of proceeding systematically, and of ultimately forming a comprehensive survey of that portion of the southern sky which is beyond the reach of northern observers. To this end Mr. Dawson confined his attention chiefly to the measurement of wide pairs which had been discovered by other observers, while Professor Hussey divided his time between searching for new pairs and the complementary measurement of those already known. This work has already resulted in the discovery of more than three hundred double stars and in securing more than three thousand observations.

The large refractor has also been used regularly for the observation of southern comets. Two hundred and one observations of ten different comets were secured in the years 1912, 1913, and 1914, and 37 observations of the minor planet (707) Interamnia. These included series of measurements of two comets discovered at La Plata, viz., Comet Westphal-Delavan, 1913, *d*, and Comet Delavan, 1913 *f*. The former was a return of Westphal's Comet of 1852, concerning whose periodic time there was so much uncertainty that it was not known in what part of the sky it would reappear. The observations secured after its rediscovery by Mr. Delavan have enabled its period to be determined with great exactness.

The second comet discovered by Mr. Delavan was new. After passing to the northern hemisphere, it was conspicuously visible to the naked eye in August, September, and October, 1914, as a circumpolar object in the latitudes of Europe and the United States. It was found ten months before perihelion passage, at a distance of nearly four hundred million miles from the sun. To be visible at such a distance its intrinsic brilliancy must have been very great, and had it not been for the circumstance that it arrived at perihelion when the earth was on the opposite side of the sun, it would scarcely have failed to be one of the great comets of history.

In the northern sky and as far south as observations can be successfully made at northern observatories, accurate positions have been found for all stars to the ninth magnitude inclusive. This condition does not obtain in the extreme southern portion of the heavens, where the positions of many stars are still inadequately known. For the solution of many astronomical problems it is desirable that the places of the southern stars should be known to the same order of completeness as in the northern sky. As a contribution in this direction observations have been inaugurated with the large meridian circle at La Plata for the determination of the places of all

stars to the ninth magnitude in the zone from 52° to 62° of south declination. This program will require about 50,000 observations, of which nearly 15,000 have already been made by Astronomers Felix Aguilar and Paul T. Delavan.

ANN ARBOR, MICHIGAN.
MARCH 20, 1915.

SILVERING MIRRORS AT LOW TEMPERATURES.

BY R. H. CURTISS.

In the directions of a large proportion of the methods for silvering mirrors, which have been proposed from time to time, we find mention or specification of temperatures above 55° F. during the period of silver deposit. In connection with the Brashear and Lundin methods, which are quite generally preferred in America at least, the recommendations with respect to temperature are fairly definite. Referring to the Brashear process we find the statement: "Operations should be performed at a temperature of 65° to 73° F. (17° to 23° C.)....If the solutions are too cold, it will be difficult to secure a coat of sufficient thickness."[1] With reference to Lundin's method it is stated that "The water for the cleaning should be lukewarm, and a trifle less for the solution."[2]

My own experience, which has been with the Brashear process almost exclusively, indicates that the precipitation of silver from the usual solutions, though relatively slow, is very complete at temperatures of 40° to 45° F.,[3] and that the production of a good mirror surface at these temperatures ought to be possible, since precipitating silver will adhere readily to a cold glass surface as actual tests, made here, show. Thus the difficulties, which have been met with in securing silver coats of sufficient thickness with cold solutions by the Brashear process, seem puzzling. However it appears probable that these difficulties may be explained simply on the basis of the fact that a lowering of the temperature of the solution causes a slower rate of precipitation of the silver. Probably in most cases of unsuccessful silvering at low temperatures, the mirror has been colder than the solution, and the chilling effect of the cold glass surface on the liquid in immediate contact with it has retarded the precipitation of silver at the very point where the formation of the free metal is required. In the meantime the silvering reaction has proceeded at a normal rate in the rest of the solution and has been completed before a coat of the desired thickness has formed on the colder mirror.

Apparently we have a difficulty here which rapid stirring will alleviate but not remove. And if much of the lack of success in silvering at low temperatures is to be accounted for in this way, it is also possible that some of the mysterious failures in silvering at the specified temperatures have been due to lack of attention to the relative temperatures of mirror and solutions during the precipitating process. At any rate the plausibility of this explanation as well as the writer's own experience suggests the formulation of this simple rule: *During the precipitating process, the mirror should not be colder than the solutions.* Ideal conditions may require a mirror temperature somewhat in excess of that of the solutions.

During the last two years there has been occasion on two winter days to silver the 37½" mirror, in its cell. On January 27, 1914, the maximum temperature was 50° F.; the minimum for the preceding night, 35°. The day was damp and cloudy. On February 19, 1915, the outside temperature at 10 a. m. was 34° F.; at 2 p. m. in the telescope dome, 44°; and at 6 p. m. outside, 34°. On both days the temperature of the air about the mirror during silvering must have been in the neighborhood of 45° F. The rule of relative temperatures, proposed above, was carefully applied, but aside from that no attempt was made to raise the temperature of the large mirror, and the solutions (of the Brashear process) were allowed to stand in the unheated telescope room for some time before use to ensure their thorough cooling. Both of these winter coats, though forming slowly (in about twenty-five minutes), were thick, easily burnished, and brilliant. The latter of these two coats was one of the best so far secured at Ann Arbor.

ANN ARBOR, MICHIGAN.
MARCH 6, 1915.

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[1] *Popular Astronomy*, Vol. 19, p. 334. In this reference, 55° is evidently a misprint.
[2] Ibid., Vol. 19, p. 336.
[3] Lower temperatures are not mentioned because of the danger of freezing before drying of the surface is complete.

THE GEOGRAPHICAL POSITION OF THE OBSERVATORY OF THE UNIVERSITY OF MICHIGAN

By RALPH H. CURTISS

THE LONGITUDE

In a letter from Professor Francis Brünnow to the Editor of the *Astronomical Journal*,[1] dated January 27, 1858, the bare statement is made that the geographical position of Ann Ann Arbor is

Latitude, 42° 16′ 48″,
Longitude, 0h 27m 12s. West from Washington.

Five months later on June 22, 1858, in a similar letter to the *Astronomical Journal* there occurred this paragraph:

> To the kindness of G. P. Bond, Esq., I owe the communication of observations of the occultations of the Pleiades on March 19, which at last has enabled me to determine our longitude. I find for it
>
> 26m 41.0s west from Washington,
>
> which will come very near the truth.[2]

This value was soon superseded however, for a telegraphic determination of the longitude of the Detroit Observatory was effected in 1861 through a connection made with the Litchfield Observatory of Hamilton College at Clinton, New York.[3] On June 29, 126 beats of the two clocks were recorded at both stations, and on July 3, 28 comparisons were made. Before and after the exchange of signals, observations of standard stars were made by Professor C. H. F. Peters, at Clinton, and by Prof. Brünnow, at Ann Arbor. Simultaneous observations established the relative personal equation of the two observers as Peters — Brünnow = + 0.04s ± 0.008s. This value in combination with the observed difference of local time at the two stations yielded the following value of the longitude difference between the two observatories.

Detroit Observatory (Meridian Circle)
—Litchfield Observatory (Transit)
= + 33m 17.73s ± 0.027s.

On August 16 and October 3, 1859, the longitude west of Cambridge of the Litchfield Observatory had been determined telegraphically by Observers, C. H. F. Peters at Clinton, and G. P. Bond, at Cambridge.[4]

After correction for personal equation the longitude difference between these two stations was found to be

Litchfield Observatory (Transit)
—Harvard College Observatory (Center of Dome)
= + 17m 6.48s ± 0.039s.

Thus the longitude difference between Ann Arbor and Cambridge was determined as

Detroit Observatory (Meridian Circle)
—Harvard College Observatory (Center of Dome)
= + 50m 24.21s ± 0.047s.

The Detroit Observatory was again connected telegraphically for longitude purposes, with Cambridge, Mass., on three nights in 1869 with Observers A. T. Mosman and F. Blake at Cambridge and Professor J. C. Watson at Ann Arbor.[5] But the record leads to the inference that no determination of the relative personal equation of the observers involved was ever made. And the results of this longitude campaign do not seem to be available. The old observations, of 1861, still furnish the accepted data upon which is based the published values of the longitude of the Detroit Observatory.

The value of the longitude difference, Detroit Observatory — Harvard College Observatory (+ 50m 24.21s ± 0.047s), combined with the published value of the longitude of the Harvard College Observatory (4h 44m 30.98s ± 0.04s west of Greenwich) as determined by the cable observations of 1866, 1870 and 1872, yielded the value, 5h 34m 55.19s ± 0.06s west of Greenwich, for the longitude of the Detroit Observatory Meridian Circle. This value of the longitude was introduced into the American Ephemeris for 1896 and has not been altered since.

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[1] *Astronomical Journal*, Vol. 5, p. 112.
[2] *Astronomical Journal*, Vol. 5, p. 145.
[3] *Astronomical Notices*, No. 27, p. 17.
[4] *Astronomical Notices*, No. 15, p. 113.
[5] *United States Coast Survey Report*, 1869, p. 15.

In 1892 longitude signals were again cabled across the Atlantic, this time between Greenwich and McGill University Observatory, Montreal, Canada; and the Montreal station was connected telegraphically with the Cambridge and Albany stations of the Longitude Net of the United Coast and Geodetic Survey. The final value[6] of the longitude west from Greenwich, of the Dome of the Harvard College Observatory at Cambridge as adjusted in June, 1897, was 4h 44m 31.046s ± 0.048s. Adding to this the above value of the longitude of Ann Arbor west of Cambridge we obtain the following improved value of the longitude west from Greenwich of the Meridian Circle of the Detroit Observatory,

5h 34m 55.256s ± 0.065s.

On three occasions longitude signals were exchanged between the Detroit Observatory and a former station of the United States Lake Survey in Detroit. Two of the resulting determinations are available. In 1861,[7] the difference of longitude of Ann Arbor and Detroit was determined by six nights exchange of signals as 2m 43.30s ± 0.046, the observers at Detroit being Lieutenant O. M. Poe and Assistant James Carr and at Ann Arbor, Professor Brünnow. In 1864[8] this difference was again determined by three nights exchange of signals as 2m 43.17s, the observers at Detroit being Col. W. F. Reynolds and Assistant S. W. Robinson and at Ann Arbor, Professor Watson. Personal equation was applied in both cases. In the second exchange of longitude signals between Ann Arbor and Detroit apparently there was no telegraph line running to the Detroit Observatory. The signals from Ann Arbor seem to have been sent from a chronometer which was carried to the telegraph office. But in discussing these determinations on page 716 of *Professional Papers, Corps of Engineers, U. S. A., No.* 24, the two determinations were given equal weight. Taking the mean then of these two results, we have 2m 43.23s. Applying the correction (—0.127s) to reduce the old transit post to the east transit post of the Lake Survey Observatory of 1871 there results

Detroit Observatory (Meridian Circle)
—East Transit Post, Lake Survey Obs. of 1871, Detroit
= + 2m 43.10s ± 0.05s,

in which the probable error is estimated from the agreement of the two sets and is indicated by the given probable error of the 1861 determination.

Through direct measurement from the neighboring longitude station of 1891, which belongs to the longitude net of the United States Coast and Geodetic Survey, the longitude of the east transit post of the Detroit Lake Survey Station of 1871 has been found to be

5h 32m 12.196s ± 0.050s[9]

which in combination with the above longitude difference between Ann Arbor and Detroit furnishes a second value for the longitude of the Meridian Circle of the Detroit Observatory west of Greenwich,

5h 34m 55.296s ± 0.07s.

Thus there are now available two determinations of the longitude of the Detroit Observatory, made some fifty years ago through telegraphic connection with stations of the longitude net of the United States Coast and Geodetic Survey. Combining these two consistent determinations and rounding off to the nearest hundredth of a second we obtain for this constant,

Longitude of the Detroit Observatory Meridian Circle
West of Greenwich,
5h 34m 55.27s ± 0.06s,

in which the dependence of the result upon the same trans-Atlantic connections is taken into account in deriving the probable error.

THE LATITUDE

The provisional value of 42° 16′ 48″ for the latitude of the Detroit Observatory as reported by Professor Brünnow in 1858, was adopted by the American Ephemeris and with the addition of a zero in the tenths place of seconds is still in use in that publication. In the meantime two accurate and independent determinations of the latitude of this Observatory have become available,

[6] *U. S. Coast and Geodetic Survey Report,* 1897, App. 2.
[7] *U. S. Lake Survey Report,* 1861.
[8] *U. S. Lake Survey Report,* 1865.
[9] *U. S. Coast Survey Report,* 1897, p. 261.

which establish a far more reliable value of that quantity.

The first of these latitude determinations was made by Dr. Ludovic Estes with the Three-Inch Transit Instrument used as a Zenith Telescope.[10] From observations upon 138 pairs of stars by Talcott's method, made between October 6, 1886, and February 9, 1887, the latitude of the Observatory was determined with the result,

$$\phi = 42^\circ\ 16'\ 48''.66 \pm 0''.051$$

referred to the Meridian Circle.

The second determination of the latitude of this observatory came as a by-product of the meridian circle observations of Professor Harriet W. Bigelow, made in the years, 1901, 1902 and 1903, for the determination of circumpolar star positions.[11] From direct and reflected observations of twenty-six stars there resulted a very consistent set of values of the latitude of the Detroit Observatory Meridian Circle, ranging from 48.″42 to 49.″35, with a mean value,

$$\phi = 42^\circ\ 16'\ 48''.76 \pm 0''.06.$$

Combining these two values of the latitude with weights depending on their probable errors we obtain the value,

$$\text{Latitude} = 42^\circ\ 16'\ 48''.70 \pm 0''.04,$$

referred to the Meridian Circle of the Detroit Observatory of the University of Michigan.

A determination of the latitude of this observatory in agreement with the above value was made by Professor A. Hall from meridian circle observations of circumpolar stars in the years, 1898-1901.

THE ELEVATION.

The elevation of the Detroit Observatory, in use for many years, probably derived from railway levels, has been taken as 936 feet or 285 meters, this being the assumed height of the cistern of the barometer. The axis of the Meridian Circle is 3.02 feet higher.

More reliable values of the altitude of the Detroit Observatory above sea level are now available, based upon a bench mark with a marked elevation of 881.861 feet, which has been placed in the south wall of the University Library by the United States Geological Survey. Results of a series of levels between this bench mark and the Observatory, run by students during the spring of 1912 have been kindly furnished by Professor H. H. Atwell of the Department of Engineering of the University of Michigan. These may well be recorded here for reference. They furnish values of the elevation of the concrete floor at the base of the first column inside the south west entrance of the 37½-Inch Reflector Dome of the Observatory, above the Library Bench Mark.

ELEVATIONS OF BASEMENT FLOOR, OBSERVATORY DOME, ABOVE LIBRARY BENCH MARK.

Party No. 1	26.24	feet
	26.14	
Party No. 2	26.20	
		27.45 rejected [1 foot (?) in error]
Party No. 3	26.15	
	26.41	
Party No. 4	26.39	
	26.15	
Party No. 5	26.05	
Mean	26.216 feet ± 0.032 feet.	

Thus we have the following result:
Elevation of Observatory Basement Floor 908.08 feet.

Levels run inside the Observatory by the writer measure the elevation of the axis of the Meridian Circle and of the cistern of the standard barometer above the basement floor of the 37½″ Reflector Dome as 18.24 feet and 15.22 feet respectively. Thus we have, referred to sea level:

The elevation of the axis, meridian circle.........926.32 ft or 282.35 meters,
The elevation of the barometer cistern ....923.30 ft or 281.42 meters.

Collecting for convenience of reference the above values of the terrestrial co-ordinates of the cube of the Meridian Circle of the Detroit Observatory we have the quantities below.

CO-ORDINATES OF THE DETROIT OBSERVATORY.

LONGITUDE, 5h 34m 55.27s ± 0.06s, West of Greenwich.

LATITUDE, 42° 16′ 48.″70 ±0″.04 North,

ELEVATION, 926.32 feet, or 282.35 meters above sea level.

The writer wishes to acknowledge the kindness of Professors Asaph Hall and Harriet W. Bigelow in verifying some of the data in this paper.

January, 1913.

[10] *Detroit Observatory Publications,* Vol. I, p. 28.

[11] *Astronomical Journal,* Vol. 24, p. 102. Also *Proceedings of the Washington Acad. of Science,* Vol. 7, pp. 189-194, 1905.

A DETERMINATION OF THE VISUAL LIGHT CURVE OF BETA LYRAE

By RALPH H. CURTISS

INTRODUCTION.

Although the discovery of the light variation of β Lyrae dates back nearly one hundred and thirty years, the determination of the conditions in the system of this star continues to be to a considerable extent, an unsolved problem. That this problem is rated as a difficult one is due in some degree to the lack of success which has attended the efforts of those who have addressed themselves to its solution with the aid of inadequate instrumental equipment. But in the main the difficulties attending the study of this problem are real ones resulting from the unusual and complicated changes which are established and suspected both in the dispersed and total light of this star. At the same time the importance of this problem is widely recognized since β Lyrae is the brightest known representative of a class of variable stars whose members are thought to illustrate the earlier stages in one type of double star evolution.

In view of the importance of the "Problem of β Lyrae" it is fortunate that we have available some 450 photometric determinations of the magnitude of this star made in four different years at the Harvard College Observatory. One set of these observations is used later on in this paper. But, in view of the relatively small number of these photometric measures, for the present and possibly for some time to come, we must depend largely on naked eye comparisons for our knowledge of the minor features and changes in the visual light curve of this star. It is therefore unfortunate that the limitations of visual methods should be so great; and at the same time it would seem of considerable importance that the psychological and other sources of uncertainty which affect visual comparisons be investigated and kept in mind.

ERRORS IN LIGHT ESTIMATES.

Argelander, whose visual comparisons of naked eye stars have set a standard of accuracy for the last seventy years, was fully alive to the importance of the sources of error which affect observations of this kind. He recognized the effect of variations of the Purkinje phenomenon in causing discrepancies between the results of different observers. He assigned due importance also to the remarkable persistent differences between estimates of different observers of the relative brightness of any two stars of the *same* color. Possibly he intended that these explanations should be extended to account for some of the variations in the results of the same observer in different years, such as his suspected variation in the brightness of δ Lyrae. Certainly these considerations must be kept in mind.

In connection with the Purkinje phenomenon it may also be considered that the apparent relative brightness of any two stars of different colors depends to some extent upon the brightness of the background of sky light.

Further, as the result of personal differences in color perception, the application of visual methods to the study of the light variations of certain short period variables may be expected to be followed by discrepancies among the results obtained by different observers, and probably among those obtained by the same observer in different years. It is well known that the variations of certain short period variables are different in different colors. We should therefore expect to find persistent differences in these cases between the results of an observer whose eyes are most sensitive to green or greenish yellow light and those of another observer whose eyes are most sensitive to yellow or yellowish red light. Very probably this effect will account for some observed discrepancies among the results of different observers as well as unexplained variations in the results of the same observer in different years.

Aside from errors due to differences in color perception there are psychological or optical difficulties which have important bearing on the pres-

ent problem. Of these we may consider first the effect on the apparent relative brightness of two stars due to changes in their relative position in the sky. Several observers have noted that of two stars of equal brightness the lower appears to them the brighter. Whether this effect depends only on the difference of altitude of the stars compared, or whether it depends on the direction of the line joining them is perhaps unknown, but probably both factors are involved. Judging from my own experience this effect is one which varies considerably in magnitude at different times, depending perhaps on the condition of the eyes as regards fatigue. The actual extent of this "hour angle effect" in my own case is considered later on in this paper.

Another recognized source of error, which may affect strongly any given series of light comparisons, is that which results from the tendency of the observer to estimate as equal, the brightness of the variable and of any comparison star from which it differs slightly. It is readily seen that this tendency may introduce minor irregularities in the form of a light curve such as those that appear often in published results.

Probably the source of error that may have the greatest effect upon any single observation is that due to mental preoccupation or bias. And the final curve may be greatly affected if the results are watched too closely, or follow at intervals so short that the mental processes attending one observation are still fresh when a second is made.

In addition, the visual estimates must share with photometric observations the uncertainties which arise from atmospheric absorption.

METHOD OF OBSERVATION.

In view of the above considerations it would seem that certain methods of attack, requiring more or less co-operation might facilitate the determination of the character and changes of the light curve of β Lyrae. For the determination of the mean brightness of this star, as well as the magnitude range, we must of course depend largely upon the results for the comparison stars obtained with the photometer. But in the determination of the form of the curve and of variations in the magnitude range, naked eye comparisons have yielded most valuable results and very probably could be made even more productive if observations were properly organized. But the feasibility of any extensive scheme of co-operation is very doubtful, and for the present it remains for each observer to follow the method of attack which in his judgment will contribute best to the solution of the problem. For the present series of observations, as described below, the writer has adopted, after some experiment, a simple system of light comparison which may be characterized as a special application of Argelander's method.

Two comparison stars only were chosen, both very near the variable. The brighter of these two stars was very nearly equal in magnitude to the variable at maximum light, while the fainter comparison star was a little fainter than β Lyrae at minimum brightness. The difference in brightness between the two comparison stars was about one and two-tenths magnitudes and in the comparisons, one-tenth of this magnitude difference was taken as the unit of measurement, and in terms of this unit the difference of brightness of the variable and the two comparison stars was estimated directly. The estimates thus made were converted into magnitude differences by the application of the proper factor, and, finally, magnitudes of the variable were obtained from the comparison star magnitudes by direct addition or subtraction of these determined differences.

In selecting this method of observation it was kept in mind that the results might not contribute definitely to our knowledge of the general form of the light curve of β Lyrae, because of the difficulty in extending the unit of measurement over the relatively large light intervals involved. But it was hoped that information might be gained with reference to phase times, minor irregularities and certain sources of error, more particularly, by a method differing somewhat from that ordinarily employed; and the nearness of the comparison stars to the variable was held to be an important consideration.

THE COMPARISON STARS.

The stars used in comparisons with β Lyrae were γ and δ of the same constellation. The

former is about two degrees and the latter about three and one-half degrees from the variable.

So far as I know, γ Lyrae has never been suspected of variability. Although different observers seem to receive distinctly different impressions of its brightness, its light seems constant in the results of any given observer and the variations noted seem to be assignable to subjective difficulties. A velocity variation of about twenty-five kilometers with a period of about twenty-five days was announced for this star by Professor S. A. Mitchell in 1909. Radial velocity observations made at this observatory indicate that the velocity range for this star is much less and the period, if it exists, much greater, than the corresponding announced values. The magnitude assigned to this star, taken from the *Revised Harvard Photometry*, is 3.30.

δ Lyrae is a visual double star the components of which have magnitudes, 4.52 and 5.51, the spectral types being Mo and B3 respectively. As the fainter star is distant about twelve minutes of arc from the primary, its light is not added to that of the primary when observed with the naked eye. At least the best assumption seems to be that such is the case. The radial velocity of the fainter star is variable in an unknown period. The radial velocity of the brighter star is constant so far as known. Argelander suspected this star of light variability though the differences between his determinations of its brightness, at different epochs, referred to neighboring stars, did not exceed 0.06 magnitudes. Subsequently other observers have used δ Lyrae as a comparison star apparently without suspicion, and from my own observations there seems to be no certainty of its variability, though recent results of Stempel and Lau suggest a light change of some character. To the present it has not found a place in catalogs of variable stars.

THE OBSERVATIONS.

Employing the above method and comparison stars, observations of the brightness of β Lyrae were begun by the writer in 1907 in connection with spectrographic observations, the results of which have already been published. The magnitude observations have been continued and the results of the first six years (1907-1913), comprising 612 observations, are discussed in this paper.

Table I contains the essentials of the Journal of Observations. Column 1 contains the observation number; column 2, the civil date in Greenwich Mean Time. The third column gives the phase time for each observation referred to the last preceding principal minimum computed on the basis of Pannekoek's revised formula,

$$T \text{ (Prin. min.)} = 1855 \text{ Jan. } 6^d.604 \text{ G. M. T.} + 12^d.908009\,E + 3^d.855\,t^2 - 0.047\,t^3,$$

where E represents the number of complete periods since the initial epoch and $t = E/1000$. In the fourth column the comparison of the variable with γ Lyrae is given according to the method described above. The unit or step is the tenth of the difference in magnitude of γ Lyrae and δ Lyrae. Observations with positive or negative signs indicate that the variable was fainter or brighter respectively than the star, γ Lyrae. In this column, there occur seven comparisons of the variable with stars other than γ and δ Lyrae. These are not reduced in this paper.

In column 5, the hour angle of the approximate region of the stars observed is given for each observation and in column 6, brief notes are copied from the observing journal. The numbers in this column refer to the phase of the moon, "4" denoting a full moon.

TABLE I. OBSERVATIONS OF β LYRAE.

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
1	June	8.73	7.14	+2.00	—1.5	
2		9.65	8.06	+1.50	—3.4	
3		11.68	10.09	—0.50	—2.6	
4		11.71	10.12	+0.00	—1.9	
5		14.73	0.22	6.50	—1.4	
6		15.61	1.10	5.00	—3.8	
7		15.61	1.10	$o1\beta3\delta$	—3.8	
8		15.61	1.10	$\beta=\theta$	—3.8	
9		16.67	2.16	2.00	—2.3	
10		17.60	3.09	0.50	—4.2	
11		17.65	3.14	0.40	—3.0	
12		17.65	3.14	$\gamma0.5\beta4.5\theta$		
13		18.65	4.14	$\gamma1\beta4\theta$	—2.9	
14		18.65	4.14	0.40		
15		20.63	6.12	3.50	—3.2	
16		20.63	6.12	$\gamma2\beta3\theta$	—3.1	

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
17		24.63	10.12	0.00	—2.8	
18		25.65	11.14	0.83	—2.4	
19		26.68	12.17	5.00	—1.4	
20		26.68	12.17	$\theta 1 \beta 10$	—1.4	
21		27.67	0.25	6.75	—1.8	
22		30.68	3.26	0.00	—1.2	
23		30.82	3.40	0.00	+2.0	
24	July	3.58	6.16	3.50	—3.4	
25		3.70	6.28	3.50	—0.7	
26		3.70	6.28	$\beta = \frac{\theta + \xi + \theta}{3}$	—0.7	
27		4.67	7.25	3.00	—1.3	Thick smoke Poor ? δ just visible
28		5.58	8.16	1.50	—3.2	Smoky
29		6.71	9.29	0.50	—0.2	
30		7.61	10.19	0.00	—2.4	
31		7.73	10.31	0.50	+0.3	
32		12.67	2.33	+0.33	—0.8	
33		12.77	2.43	—0.33	+1.7	
34		13.69	3.35	+0.15	—0.8	
35		14.71	4.37	2.00	—0.4	
36		14.74	4.40	1.00	+0.3	
37		17.71	7.37	3.50	+0.6	
38		18.60	8.26	1.25	—1.7	
39		18.81	8.47	0.50	+3.0	
40		20.63	10.29	0.25	—1.2	
41		20.71	10.37	1.00	+0.8	
42		[illegible].83	10.49	0.00	+3.8	
43		23.65	0.39	7.25	—0.5	Bright moon
44		23.75	0.49	7.00	+2.0	Bright moon
45		24.65	1.39	3.00	—0.5	Moon
46		26.62	3.36	0.00	—0.8	Moon
47		26.78	3.52	0.33	+2.2	Moon
48		27.71	4.45	0.25	+1.2	Moon
49		29.71	6.45	3.00	+1.4	
50		30.58	7.32	2.50	—1.6	
51		30.73	7.47	2.00	+1.9	
52	Aug.	1.58	9.32	0.33	—1.5	
53		1.71	9.45	0.50	+1.5	
54		1.79	9.53	0.50	+3.5	
55		2.71	10.45	1.00	+1.6	
56		3.82	11.56	2.25	+4.4	
57		4.60	12.34	5.50	—0.7	
58		6.65	1.47	4.25	+0.4	
59		6.73	1.55	2.00	+2.4	
60		7.58	2.40	0.25	—1.1	
61		7.65	2.47	0.25	+0.6	
62		7.75	2.57	0.00	+2.9	
63		9.65	4.47	0.00	+0.6	
64		9.80	4.62	1.00	+4.4	
65		10.62	5.44	2.25	+0.2	
66		11.62	6.44	3.75	+0.2	
67		11.67	6.49	4.00	+1.2	
68		11.81	6.63	3.33	+4.7	
69		12.62	7.44	2.25	+0.3	
70		13.65	8.47	0.50	+0.8	
71		13.73	8.55	0.00	+2.8	
72		14.65	9.47	0.25	+0.9	
73		15.60	10.42	0.50	±0.0	
74		15.75	10.57	0.75	+2.5	
75		17.65	12.47	6.25	+1.1	
76		18.73	0.63	5.75	+3.0	
77		19.54	1.44	3.00	—1.3	
78		19.65	1.55	2.00	+1.2	
79		19.71	1.61	1.25	+2.7	
80		19.74	1.64	0.75	+3.4	
81		22.56	4.46	0.25	—0.6	
82		24.67	6.57	3.00	+2.1	
83		25.56	7.46	4.00	—0.4	
84		25.73	7.63	2.25	+3.6	
85		25.75	7.65	2.25	+4.1	
86		26.56	8.46	0.25	—0.3	
87		28.73	10.63	0.50	+3.8	
88		30.67	12.57	7.25	+2.5	Faint
89		31.60	0.58	7.75	+1.0	
90		31.71	0.69	7.50	+3.5	
91	Sept.	1.69	1.67	5.00	+3.1	Smoky
92		5.60	5.58	1.00	+1.4	
93		6.54	6.52	1.75	—0.1	
94		6.71	6.69	2.50	+3.9	
95		12.63	12.60	7.75	+2.0	
96		18.54	5.60	0.75	+0.4	Full moon
97		19.59	6.65	5.00	+1.7	Full moon
98		19.67	6.73	4.00	+3.5	Full moon
99		20.59	7.65	1.50	+1.8	
100		22.54	9.60	+0.00	+0.7	
101		22.62	9.68	—1.00	+2.7	
102		24.54	11.60	+0.00	+0.8	
103		24.65	11.71	+0.75	+3.3	
104		30.54	4.68	0.00	+1.2	
105		30.67	4.81	0.50	+4.2	
106	Oct.	1.69	5.83	2.50	+4.5	
107		2.67	6.81	2.50	+4.3	
108		4.67	8.81	+0.75	+4.5	
109		5.54	9.68	—0.50	+1.5	
110		5.67	9.81	—0.25	+4.5	
111		6.67	10.81	+0.25	+4.6	
112		8.67	12.81	10.00?	+4.7	Eyes tired
113		9.62	0.84	8.00	+3.8	
114		9.69	0.91	7.25	+5.3	
115		14.58	5.80	1.75	+3.1	Moon
116		14.67	5.89	2.25	+5.1	Moon
117		16.58	7.80	1.00	+3.2	Moon
118		17.62	8.84	0.25	+4.3	Full moon
119		18.54	9.76	0.25	+2.4	Full moon
120		18.67	9.89	0.00	+5.4	Full moon
121		20.68	11.90	3.33	+5.8	Moon
122		21.67	12.89	9.00	+5.6	Moon
123		23.6±	1.90	1.00	+3.7	
124		25.48	3.78	+0.00	+1.3	
125		25.58	3.88	—0.50	+3.8	

NO.	DATE 1907	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
126		29.52	7.82	+1.00	+2.6	
127	Nov.	7.46	3.84	—0.25	+1.7	
128		8.56	4.94	+0.25	+4.2	
129		12.60	8.98	0.75	+5.5	
130		22.50	5.96	1.50	+2.7	
131		23.52	6.98	2.75	+3.2	
132	Nov.	26.48	9.94	0.50	+3.4	
	1908					
133	Jan.	5.48	11.19	0.33	+6.0	
134	April	16.73	10.08	0.00	—5.2	
135		21.69	2.12	0.75	—5.9	
136		25.71	6.14	4.00	—5.1	
137		29.71	10.14	0.25	—4.9	
138	May	2.75	0.26	7.50	—3.7	
139		9.71	7.22	1.50	—4.2	2
140		11.75	9.26	0.50	—3.1	—
141		15.71	0.30	7.00	—3.0	—
142		21.62	6.21	4.00	—5.4	0
143		21.73	6.32	4.25	—2.9	0
144		22.69	7.28	2.00	—3.8	0
145		22.71	7.30	1.75	—3.3	0
146		23.62	8.21	+1.00	—5.4	0
147		23.83	8.42	—0.50	—0.4	0
148		24.62	9.21	+0.75	—5.2	0
149		26.67	11.26	0.75	—4.1	0
150		26.75	11.34	1.50	—2.1	0
151		27.73	12.32	6.00	—2.5	0
152		28.69	13.28 (0.36)	8.00	—3.5	0
153		30.67	2.34	0.00	—3.8	0
154	June	1.71	4.38	0.50	—2.7	0
155		2.69	5.36	1.75	—3.1	0
156		3.71	6.38	3.50	—2.6	0
157		4.69	7.36	2.00	—3.0	—
158		6.65	9.32	0.50	—4.3	—
159		11.62	1.37	5.00	—4.0	3
160		11.71	1.46	5.00	—2.0	3
161		19.67	9.42	0.50	—2.5	0
162		20.71	10.46	0.00	—1.5	0
163		21.67	11.42	0.50	—2.4	0
164		22.75	12.50	7.50	—0.3	Sky thick 0
165		23.62	13.37 (0.46)	8.50	—3.3	
166		24.62	1.46	4.00	—3.2	
167		25.67	2.51	0.75	—2.1	
168		26.62	3.46	0.50	—3.1	
169		27.67	4.51	0.00	—2.0	—
170		28.77	5.61	2.00	+0.6	—
171	July	4.71	11.55	2.00	—0.5	—
172		5.65	12.49	6.25	—2.0	1
173		7.67	1.59	2.50	—1.3	2
174		10.65	4.57	0.00	—1.6	3
175		12.67	6.59	2.50	—1.0	4
176		14.65	8.57	0.50	—1.4	4
177		15.67	9.59	0.00	—0.8	3
178		18.65	12.57	7.50	—1.1	0
179		19.67	0.67	7.00	—0.6	0

NO.	DATE 1908	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
180		26.60	7.60	2.75	—1.4	—
181		28.62	9.62	0.00	—0.8	—
182		29.62	10.62	0.75	—0.7	0
183		30.58	11.58	2.75	—1.6	0
184	Aug.	2.58	1.66	2.75	—0.9	0
185		9.58	8.66	1.00	—0.5	4
186		10.60	9.68	0.25	+0.1	4
187		11.60	10.68	0.00	+0.2	4
188		14.60	13.68 (0.76)	5.50	+0.5	Moon faint
189		20.60	6.76	3.75	+0.8	0
190		23.56	9.72	0.00	±0.0	0
191		24.62	10.78	0.50	+1.5	0
192		27.65	0.89	5.50	+1.7	
193		28.56	1.80	1.00	+0.3	
194		29.62	2.86	0.00	+1.9	0
195		30.62	3.86	0.00	+1.9	0
196	Sept.	7.65	11.89	3.00	+1.7	3
197		8.62	12.86	7.00	+1.8	4
198		9.62	0.94	5.00	+1.9	4
199		10.62	1.94	0.00	+1.9	4
200		14.67	5.99	0.75	+3.2	2
201		16.56	7.88	0.25	+0.8	0
202		17.62	8.94	0.00	+2.4	0
203		18.62	9.94	0.00	+2.5	Sky thick
204		21.54	12.86	+7.75	+0.7	Sky thick
205		24.67	3.07	—0.50	+3.8	0
206		26.62	5.02	—0.00	+3.0	
207		27.62	6.02	+0.25	+3.0	
208		29.62	8.02	0.00	+3.2	0
209		30.62	9.02	—0.50	+3.3	
210	Oct.	1.67	10.07	—0.50	+4.3	0
211		2.62	11.02	+0.25	+3.4	0
212		3.60	12.00	3.50	+2.9	2
213		4.62	0.10	+7.00	+3.5	3
214		10.67	6.15	—0.25	+4.9	4
215		11.54	7.02	+2.75	+2.0	0
216		12.54	8.02	1.00	+2.0	0
217		12.69	8.17	0.25	+5.5	2
218		13.67	9.15	0.00	+5.1	2
219		14.67	10.15	—0.25	+5.2	2
220		15.67	11.15	—0.50	+5.3	1
221		18.58	1.14	+3.25	+3.4	0
222		19.67	2.23	0.00	+5.5	0
223		23.56	6.12	+0.75	+3.3	0
224		25.62	8.18	—0.50	+4.9	0
225		30.52	0.16	+7.25	+2.7	1
226	Nov.	1.58	2.22	+0.25	+4.2	2
227		2.54	3.18	—0.25	+3.4	2
228		3.54	4.18	0.00	+3.5	2
229		4.54	5.18	0.00	+3.6	2
230		6.52	7.16	+2.25	+3.2	4
231		8.50	9.14	—1.00	+2.8	
232		9.50	10.14	—0.25	+2.9	
233		11.54	12.18	+0.75	+4.0	
234		11.62	12.26	4.00	+6.0	2
235		12.52	0.24	8.25	+3.6	0

NO.	DATE 1908	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
236		12.62	0.34	7.75	+6.0	2
237		13.54	1.26	+1.75	+4.1	
238		14.52	2.24	0.00	+3.7	
239		15.50	3.22	—1.25	+3.3	0
240		20.50	8.22	0.00	+3.6	0
241		21.50	9.22	—2.00	+3.7	0
242		24.52	12.24	+2.75	+4.4	0
243		26.54	1.34	0.00	+5.0	0
244		27.50	2.30	—1.00	+4.0	—
245		28.50	3.30	—1.25	+4.1	1
246		30.54	5.34	0.00	+5.2	1
247	Dec.	1.52	6.32	+1.25	+4.8	1
248		2.60	7.40	1.50	+6.9	1
249		9.50	1.38	2.50	+4.8	4
	1909					
250	April	22.71	6.40	4.50	—5.3	—
251		25.69	9.38	0.50	—5.7	—
252		27.71	11.40	1.75	—5.0	—
253	May	7.67	8.44	3.50	—5.3	3
254		10.62	11.39	2.25	—6.2	0
255		12.67	0.52	8.50	—5.0	0
256		22.71	10.56	1.25	—3.4	0
257		28.67	3.60	0.50	—4.0	2
258		29.71	4.64	1.00	—2.9	2
259	June	1.71	7.64	1.25	—2.8	3
260		11.67	4.68	1.50	—3.1	0
261		13.62	6.63	5.00	—3.9	0
262		15.62	8.63	2.00	—3.8	0
263		16.62	9.63	3.00	—3.9	—
264		17.65	10.66	0.50	—3.4	—
265		18.65	11.66	0.50	—3.3	0
266		19.67	12.68	7.00	—2.7	0
267		20.65	0.74	7.00	—3.2	0
268		24.75	4.84	+1.00E	—0.2	0
269		24.75	4.84	—1.00W	—0.2	—
270		28.62	8.71	+0.50	—3.0	2
271		29.71	9.80	+0.50E	—1.2	3
272		29.71	9.80	—0.50W	—1.2	—
273	July	1.71	11.80	+4.00E	—0.9	4
274		1.71	11.80	2.00W	—0.9	
275		5.75	2.92	+1.00E	+0.5	—
276			2.92	—1.00W	+0.5	—
277		6.71	3.88	+1.00E	—0.4	3
278			3.88	—2.00W	—0.4	3
279		7.71	4.88	+1.00E	—0.3	2
280		7.71	4.88	—0.50W	—0.3	2
281		8.62	5.79	+3.25	—2.3	0
282		9.67	6.84	+6.75	—1.2	0
283		12.79	9.96	—1.50W	+2.0	0
284		15.75	0.00	+7.75E	—1.2	0
285		16.75	1.00	3.25E	—1.1	0
286		18.67	2.92	0.50W	—0.6	0
287		19.71	3.96	0.00SW	+0.4	0
288		21.71	5.96	0.00SW	+0.6	0
289		25.67	9.92	1.00W	—0.2	2

NO.	DATE 1909	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
290	Aug.	3.62	5.95	2.00E	—0.6	3
291		3.75	6.08	1.50W	—0.6	
292		4.75	7.08	+1.50W	+2.5	2
293		6.75	9.08	—1.00W	+2.6	2
294		8.67	11.00	0.00W	+0.7	0
295		20.71	10.12	0.00W	+2.5	0
296	Sept.	8.73	3.30	—0.50SW	+1.9	0
297		9.73	4.30	0.00SW	+2.0	0
298		10.73	5.30	+2.00SW	+2.1	0
299		11.79	6.36	5.00SW	+3.6	0
300		12.75	7.32	+2.00SW	+2.7	0
301		13.75	8.32	—0.50SW	+2.8	0
302		14.77	9.34	—1.00SW	+3.3	0
303		18.70	0.35	+8.50SW	+2.0	0
304		19.70	1.35	0.50SW	+2.1	0
305		20.73	2.38	0.50SW	+2.7	0
306		24.70	6.35	5.50SW	+2.4	2
307		25.70	7.35	+4.50SW	+2.5	3
308		26.70	8.35	—0.50SW	+2.6	3
309		28.73	10.38	0.00SW	+3.1	4
310		29.71	11.36	+0.50SW	+3.8	4
311	Oct.	5.56	4.29	0.00SW	+2.1	0
312		6.56	5.29	1.00SW	+2.2	0
313		14.71	0.52	8.50SW	+6.2	0
314		18.67	4.48	1.50SW	+5.4	0
315		30.62	3.52	0.00	+5.2	3
316	Nov.	3.58	7.48	1.00SW	+4.5	0
317		6.54	10.44	0.50	+3.7	0
318		10.50	1.48	2.50	+2.9	0
319		25.54	3.60	0.00	+4.9	4
320		26.58	4.64	0.50	+6.0	4
321		27.54	5.60	3.00	+5.0	4
322		29.58	7.64	+2.50	+6.2	3
323		30.54	8.60	—0.25	+5.2	0
324	Dec.	8.46	3.60	+0.12	+3.8	0
	1910					
325	April	13.73	0.67	6.75	—5.5	0
326	May	5.67	9.69	0.25	—5.5	0
327		12.71	3.81	1.00	—4.1	1
328		13.71	4.81	1.00	—4.0	1
329		14.63	5.73	2.00	—5.9	2
330		14.83	5.93	4.00	—0.9	—
331		15.83	6.93	6.00	—0.8	0
332		24.75	2.93	+0.00	—2.3	4
333		25.75	3.93	—0.25	—2.2	4
334		26.75	4.93	0.00	—2.1	3
335	June	5.71	1.97	+0.75	—2.5	0
336		6.67	2.93	0.00	—3.4	0
337		7.67	3.93	0.50	—3.3	0
338		9.67	5.93	2.50	—3.2	0
339		12.71	8.97	0.00	—2.0	0
340		15.67	11.93	1.50	—2.8	2
341		16.75	0.09	8.00	—0.8	3
342		18.71	2.05	1.50	—1.6	3
343		19.71	3.05	0.50	—1.5	3

NO.	DATE 1910	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
344		21.71	5.05	0.50	—1.4	4
345		22.75	6.09	2.50	—0.3	4
346		24.71	8.05	1.00	—1.2	4
347		27.67	11.01	0.50	—2.0	0
348		28.67	12.01	3.75	—1.9	0
349	July	4.67	5.09	1.00	—1.6	0
350		7.71	8.13	+1.00	—0.4	0
351		8.71	9.13	—0.50	—0.3	0
352		9.63	10.05	+0.00	—2.2	0
353		10.67	11.09	0.25	—1.2	0
354		12.71	0.21	8.25	—0.1	0
355		13.67	1.17	6.00	—1.0	2
356		17.67	5.17	0.50	—0.7	3
357		18.67	6.17	3.00	—0.6	4
358		19.67	7.17	3.50	—0.6	4
359		20.63	8.13	1.25	—1.5	4
360		24.63	12.13	3.25	—1.3	0
361		25.67	0.25	8.00	—0.2	3
362		27.67	2.25	+0.75	—0.1	0
363		28.67	3.25	—0.25	±0.0	0
364		29.71	4.29	+0.25	+1.1	0
365		30.63	5.21	3.50	—0.9	0
366		31.63	6.21	2.00	—0.8	0
367	Aug.	2.67	8.25	0.50	+0.3	0
368		3.63	9.21	+0.00	—0.8	0
369		4.63	10.21	—0.50	—0.7	0
370		5.67	11.25	+1.50	+0.5	0
371		6.58	12.16	1.50	—1.4	0
372		8.71	1.37	2.75	+1.7	0
373		10.67	3.33	0.50	+0.8	0
374		12.71	5.37	0.50	+2.0	0
375		18.67	11.33	0.50	+1.2	4
376		19.75	12.41	5.00	+3.2	4
377		20.71	0.45	8.00	+2.5	0
378		26.58	6.32	4.00	—0.1	0
379		27.58	7.32	3.00	±0.0	0
380	Sept.	7.63	5.45	0.50	+1.5	0
381		8.63	6.45	6.50	+1.6	0
382		14.71	12.53	6.00	+4.0	3
383		16.58	1.48	1.50	+1.1	4
384		19.63	4.53	0.00	+2.3	4
385		27.71	12.61	9.00	+5.0	0
386		28.71	0.69	8.00	+5.1	0
387		29.54	1.52	0.00	+1.1	0
388	Oct.	1.58	3.56	0.50	+2.3	0
389		2.54	4.52	0.00	+1.3	0
390		4.54	6.52	1.00	+1.5	0
391		6.67	8.65	1.00	+4.6	0
392		7.67	9.65	+0.50	+4.7	0
393		8.63	10.61	—0.50	+3.7	0
394		9.54	11.52	+0.50	+1.8	2
395		10.54	12.52	9.00	+1.8	2
396		11.54	0.60	9.00	+1.9	2
397		11.67	0.73	8.00	+4.9	2
398		13.67	2.73	0.00	+5.1	3
399		16.63	5.69	1.50	+4.3	

NO.	DATE 1910	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
400		23.58	12.64	7.75	+3.7	0
401		25.50	1.64	0.75	+1.8	0
402		25.67	1.81	+0.50	+5.8	0
403		28.58	4.72	—0.50	+4.0	0
404		31.54	7.68	0.00	+3.2	0
405	Nov.	3.58	10.72	0.00	+4.5	0
406		4.50	11.64	+0.25	+2.5	0
407		4.63	11.77	0.75	+5.5	0
408		5.54	12.68	+7.50	+3.6	0
409		8.50	2.72	—0.25	+2.8	0
410		19.58	0.88	+4.50	+5.5	2
411		20.50	1.80	0.50	+3.6	0
412		26.50	7.80	+1.25	+4.0	0
413	Dec.	4.54	2.92	—0.25	+5.5	0
414		9.54	7.92	+0.50	+5.8	2
415		12.52	10.90	0.50	+5.5	2
416		20.52	5.98	1.00	+6.0	0
417		21.50	6.96	1.50	+5.6	0
418		23.50	8.96	0.00	+5.7	0
419		26.50	11.96	1.50	+5.9	0
	1911					
420	Apr.	16.67	6.86	5.00	—6.8	3
421		17.67	7.86	1.00	—6.7	0
422		22.71	12.90	8.00	—5.4	0
423		24.71	1.98	0.50	—5.3	0
424		25.71	2.98	0.00	—5.2	0
425	May	2.75	10.02	0.00	—3.7	0
426		3.75	11.02	1.00	—3.6	0
427		4.79	12.06	5.00	—2.6	0
428		5.75	0.10	7.25	—3.5	2
429		6.71	1.06	5.50	—4.5	2
430		7.75	2.10	1.00	—3.4	2
431		10.75	5.10	2.00	—3.2	3
432		12.71	7.06	4.25	—4.1	4
433		13.75	8.10	1.00	—3.0	4
434		17.71	12.06	4.50	—3.7	0
435		18.79	0.22	8.50	—1.7	0
436		23.71	5.14	2.50	—3.2	0
437		24.79	6.22	1.75	—1.3	0
438		25.75	7.18	3.50	—2.2	0
439		26.79	8.22	1.50	—1.1	0
440		30.75	12.18	2.75	—1.9	0
441		31.75	0.26	7.75	—1.8	0
442	June	1.75	1.26	2.50	—1.8	0
443		2.75	2.26	0.75	—1.7	1
444		5.75	5.26	0.50	—1.5	2
445		8.75	8.26	1.00	—1.2	3
446		9.71	9.22	0.50	—2.2	4
447		10.67	10.18	0.50	—3.2	4
448		11.75	11.26	0.50	—1.1	4
449		13.75	0.34	9.00	—1.0	3
450		14.67	1.26	5.50	—2.9	0
451		18.67	5.26	1.00	—2.6	0
452		19.71	6.30	1.50	—1.6	0
453		20.67	7.26	2.50	—2.5	0

NO.	DATE 1911	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
454		21.67	8.26	1.00	—2.4	0
455		22.67	9.26	0.50	—2.4	0
456		23.67	10.26	0.50	—2.3	0
457		26.71	0.38	7.50	—1.1	0
458		27.71	1.38	1.75	—1.0	0
459		28.71	2.38	0.00	—1.0	0
460		29.67	3.34	0.00	—1.9	0
461		30.67	4.34	0.00	—1.8	0
462	July	1.71	5.38	1.25	—0.8	0
463		3.67	7.34	3.50	—1.6	2
464		5.71	9.38	+0.50	—0.5	3
465		6.75	10.42	—0.50	+0.6	3
466		7.71	11.38	+1.50	—0.4	3
467		8.79	12.46	7.50	+1.7	
468		9.75	0.50	7.50	+0.7	
469		11.67	2.42	0.50	—1.1	4
470		11.79	2.54	0.00	+1.9	4
471		12.63	3.38	0.00	—2.1	0
472		13.71	4.46	0.50	±0.0	4
473		14.63	5.38	2.75	—1.9	0
474		17.63	8.38	2.25	—1.7	0
475		19.75	10.50	0.50	+1.4	0
476		20.67	11.42	1.50	—0.5	0
477		21.67	12.42	6.50	—0.5	0
478		22.71	0.54	6.50	+0.6	0
479		23.67	1.50	0.50	—0.3	0
480		26.67	4.50	1.00	—0.1	0
481		27.83	5.66	3.00	+3.9	0
482		28.67	6.50	2.50	±0.0	0
483		29.67±	7.50	1.00	+0.1	0
484		30.63	8.46	0.50	—0.9	0
485	Aug.	4.63	0.54	8.00	—0.6	3
486		6.79	2.70	0.00	+3.6	4
487		8.67	4.58	0.50	+0.7	4
488		15.79	11.70	1.25	+4.2	2
489		17.58	0.57	8.00	—0.7	0
490		18.63	1.62	3.00	+0.4	0
491		19.75	2.74	0.00	+3.4	0
492		20.75	3.74	0.00	+3.5	0
493		28.75	11.74	1.00	+3.6	0
494		29.75	12.74	5.50	+4.1	0
495		30.75	0.82	6.00	+4.2	0
496		31.67	1.74	1.50	+2.2	2 low
497	Sept.	1.67.	2.74	+0.00	+2.3	2
498		2.63	3.70	—1.00	+1.4	2
499		3.67	4.74	+0.00	+2.4	3
500		5.67	6.74	+4.50	+2.6	3
501		9.63	10.70	—0.50	+1.8	4
502		12.63	0.78	+6.50	+2.0	2
503		13.67	1.82	1.50	+3.1	2
304		16.63	4.78	0.50	+2.3	0
505		17.58	5.73	0.75	+1.4	0
506		18.63	6.78	2.00	+2.4	0
507		23.67	11.82	1.50	+3.7	0
508		27.67	2.90	0.50	+4.0	0
509	Oct.	2.67	7.90	0.50	+4.3	3

NO.	DATE 1911	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
510		7.58	12.81	+7.50	+2.7	4
511		11.63	3.94	—0.50	+3.9	3
512		18.50	10.81	—1.00	+1.4	0
513		22.71	2.10	+0.00	+6.7	
514		25.54	4.93	+1.50	+2.8	0
515		27.71	7.10	3.50	+7.0	0
516		28.54	7.93	+0.00	+3.0	1
517		29.50	8.89	—0.50	+2.1	2
518	Nov.	8.50	5.97	+0.50	+2.8	3
519		15.58	0.13	8.25	+5.2	0
520		22.50	7.05	2.25	+3.7	0
521		29.50	1.13	+4.50	+4.1	2
522		30.54	2.17	—0.25	+5.2	2
523	Dec.	13.50	2.21	0.00	+5.1	0
524		22.50	11.21	0.00	+5.7	0
525		28.50	4.29	0.00	+6.2	2
	1912					
526	Mch.	16.83	6.10	+5.00	—4.8	0
527		19.79	9.06	0.00	—5.6	0
528		22.83	12.10	5.00	—4.4	
529		24.83	1.18	5.50	—4.2	0
530		26.75	3.10	0.50	—6.1	2
531		29.79	6.14	3.00	—4.9	3
532	April	5.75	0.17	8.00	—5.4	2
533		10.71	5.13	2.25	—6.1	0
534		14.75	9.17	1.50	—4.8	0
535		15.75	10.17	0.50	—4.8	0
536		24.79	6.29	4.00	—2.8	2
537		26.75	8.25	1.00	—4.1	3
538		27.71	9.21	0.50	—5.0	3
539		30.71	12.21	5.50	—4.8	4
540	May	8.79	7.37	3.75	—2.3	0
541		9.63	8.21	0.75	—6.3	0
542		14.71	0.37	6.75	—3.9	0
543		17.75	3.41	1.00	—2.7	0
544		24.79	10.45	0.50	—1.2	2
545		25.67	11.33	0.50	—4.2	3
546		30.75	3.49	0.25	—1.8	4
547		31.75	4.49	0.00	—1.8	4
548	June	2.71	6.45	4.50	—1.6	0
549		4.67	8.41	0.50	—1.5	0
550		6.75	10.49	0.50	—1.4	0
551		8.75	12.49	6.75	—1.2	0
552		9.67	0.49	7.50	—3.2	0
553		10.75	1.57	4.50	—1.1	0
554		13.79	4.61	0.25	+0.1	0
555		21.75	12.57	6.50	—0.4	2
556		22.71	13.53	7.00	—1.3	2
557		30.67	8.57	1.25	—1.8	4
558	July	2.67	10.57	0.50	—1.7	0
559		3.75	11.65	0.50	+0.4	2
560		6.67	1.65	2.00	—1.4	0
561		9.71	4.69	2.00	—0.2	0
562		10.71	5.69	0.50	—0.1	0
563		11.71	6.69	3.50	—0.1	0
564		17.71	12.69	5.00	+0.3	0

NO.	DATE 1912	GR.M.T. DAYS	PHASE DAYS	COMPAR. STEPS	HR. ANGLE HOURS	NOTES
565		18.67	0.73	7.25	—0.6	0
566		22.67	4.73	1.50	—0.3	2
567		29.58	11.64	2.25	—1.9	0
568		31.71	0.85	6.50	+1.2	2
569	Aug.	2.67	2.81	0.50	+0.4	2
570		6.67	6.81	5.00	+0.6	0
571		11.67	11.81	0.00	+1.0	0
572		15.67	2.89	0.00	+1.2	0
573		20.71	7.93	+0.50	+2.6	0
574		21.75	8.97	—1.00	+3.6	0
575		26.63	0.93	+4.50	+1.0	4
576	Sept.	3.58	8.88	+0.50	+0.4	0
577		5.67	10.97	—0.50	+2.5	0
578		6.58	11.88	+0.50	+0.6	0
579		7.58	12.88	5.75	+0.6	0
580		8.58	0.96	5.00	+0.7	0
581		9.58	1.96	0.50	+0.8	0
582		11.58	3.96	0.00	+0.9	0
583		12.58	4.96	0.00	+1.0	0
584		15.63	8.01	+0.00	+2.2	0
585		18.63	11.01	—0.50	+2.4	1
586		22.67	2.13	—0.25	+3.6	2
587		23.63	3.09	—1.00	+2.7	3
588		26.63	6.09	+1.00	+2.9	4
589		29.67	9.13	0.00	+4.2	3
590	Oct.	1.67	11.13	0.25	+4.3	2
591		2.58	12.04	0.50	+2.4	0
592		4.58	1.12	0.50	+2.5	0
593		5.67	2.21	+0.00	+4.6	0
594		12.67	9.21	—0.50	+5.0	0
595		13.71	10.25	+0.00	+6.1	0
596		16.58	0.20	8.25	+3.3	1
597		19.63	3.25	0.00	+4.5	2
598		20.54	4.16	0.50	+2.6	3
599		24.58	8.20	0.50	+3.8	4
600		26.67	10.29	+0.50	+6.0	4
601	Nov.	7.50	9.20	—0.50	+2.7	0
602		10.54	12.24	+1.50	+3.9	0
603		15.50	4.28	—0.25	+2.9	1
604		20.50	9.28	0.00	+3.6	3
605		27.50	3.36	—0.50	+4.2	0
606		30.46	6.32	+3.00	+3.3	0
607	Dec.	4.46	10.32	—0.25	+3.5	0
608		7.50	0.44	+7.50	+4.7	0
609		7.50	0.44	$\beta=\zeta$	+4.7	
610		9.50	2.44	0.00	+4.8	0
611		12.50	5.44	0.00	+5.0	1
612		14.50	7.44	+2.50	+5.2	2
613		17.50	10.44	—0.25	+5.4	2
614		22.50	2.52	+1.00	+5.7	4
615		28.50	8.52	0.00	+6.1	0
	1913					
616	Jan.	4.50	2.60	0.00	+6.6	0
617		8.50	6.60	2.25	+6.8	0
618		9.50	7.60	1.25	+6.9	0
619	Feb.	8.87	12.13	+4.25	—6.1	0

REDUCTIONS.

In the reductions the observations of each year were first treated separately in order to bring out any changes in the light curve. The light estimates for each year were arranged in order of phase and were combined into normal places in groups of from three to six observations. These results for all six years were then plotted on a large scale upon one graph in a manner calculated to facilitate the detection of variations from year to year.

As no yearly variations were surely established the entire set of 612 observations was then reduced in the same manner, the resulting normal places containing from eight to eleven observations but in most cases ten, as indicated in Table II. The resulting sixty-one mean values of the brightness of β Lyrae were plotted against the corresponding phase times and through the points so determined the preliminary light curve was drawn.

The residual for each of the original single estimates was then scaled off from this curve. These residuals with the corresponding hour angles were arranged in order of increasing hour angle and were combined into eighteen normal places each of which furnished a value of the mean residual, from the mean curve, corresponding to a mean hour angle. These normal places supplied the data from which the preliminary hour angle correction curve was directly drawn. However it was soon apparent that the amplitude of the hour angle correction curve, giving the error affecting any light estimate due to the relative position of the stars in the sky, depended on the brightness of the variable. Very probably when the variable was faint the star, δ Lyrae, was taken more directly into account in the observations and its position with reference to the variable entered more directly into the result. Accordingly the observations were divided into three classes; those within a step and a half of γ Lyrae, those between one and a half and four steps fainter than γ Lyrae, and those more than four steps fainter than γ Lyrae. For each of these classes the error curve depending upon hour angle was then determined. Finally the

correction to each one of the original 612 estimates was taken from the proper hour angle error curve and from these the corresponding correction to each of the original sixty-one normal places was derived.

At this point the probable error of a single estimate of the brightness of the variable was determined for an observation in each of the three classes of observations mentioned above. And on the basis of these probable errors six of the original observations were rejected in accordance with a careful application of the usual criterion.

As a final measure, to examine the effect on the light curve of any chance grouping of the observations in the normal places, new means were formed in which the single estimates were combined in groups of five. And also a new set of normal places containing ten observations each were formed by combining the first five observations of each of the original normal places with the last five of the preceding normal place.

THE RESULTS.

The curves representing the character and extent of the variation, with changing hour angle, of the apparent brightness of β Lyrae referred to the comparison stars are reproduced in Plate XV. Horizontally the large squares on the diagram represent hours of hour angle; vertically they represent one of the units (0.12 magn.) used in the light comparisons. Originally the observations of the first as well as the second light maximum were reduced separately but the resulting curves were so nearly identical that it was considered best to combine them into one graph. The lower curve, therefore, is based upon all the observations of the variable within one and one-half steps of γ Lyrae. The second curve results from a study of the observations near secondary minimum and at the phases before and after principal minimum when the brightness of the variable was in the neighborhood of that at secondary minimum. The upper curve is based on the observations near the principal minimum.

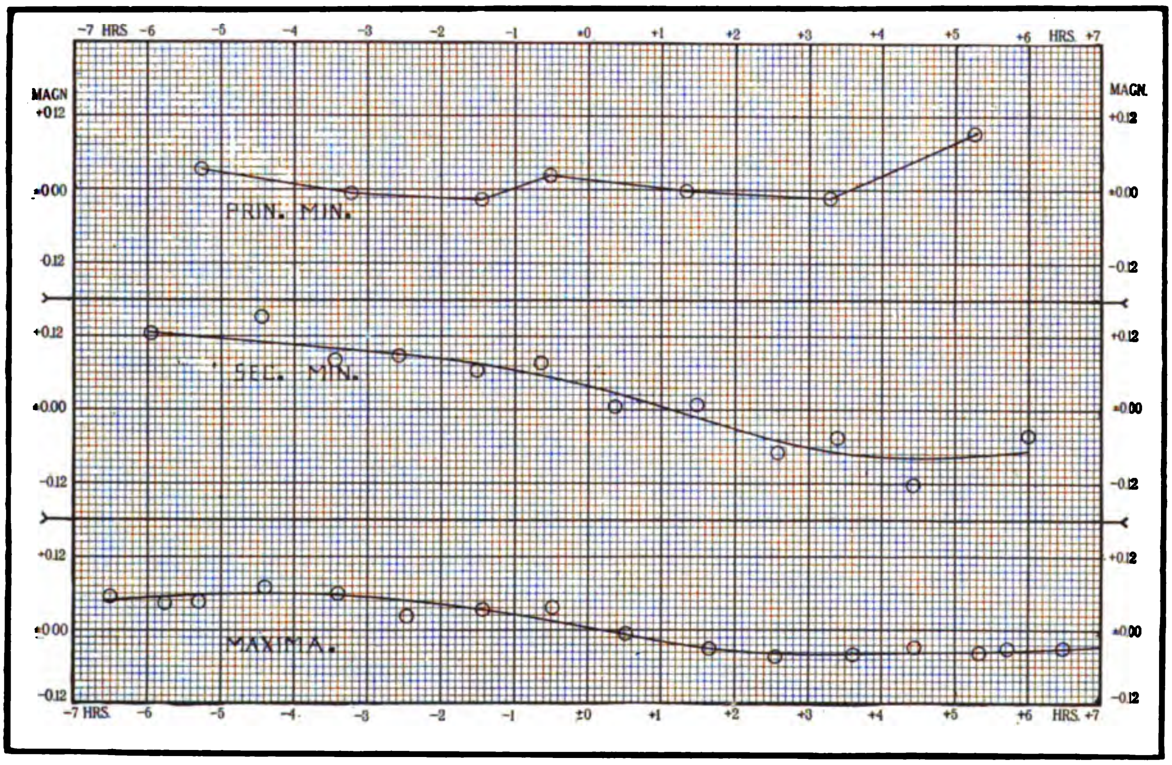

PLATE XV. CURVES EXHIBITING THE HOUR ANGLE EFFECT UPON ESTIMATES OF THE BRIGHTNESS OF β LYRAE.

A study of these curves indicates that the double amplitude of this effect is about eight one-hundredths of a step or about one-tenth of a magnitude when the variable and comparison star are of nearly the same brightness. As the difference in brightness of comparison and variable becomes larger the amplitude of this curve seems to increase very markedly. But when the variable becomes comparable in brightness with the fainter comparison star lying in a new direction there seems to be no well established dependence of the errors of estimations upon hour angle changes. Thus it is evident that this effect is a complicated one related very probably to the distance between the two compared stars, the relative brightness of the two stars, and the angle between the line joining the two stars and a vertical line passing through a point midway between them. Also this effect includes differences due to variation of the relative atmospheric absorption of variable and comparison stars with changing hour angle.

In any given case, it will be difficult to eliminate this effect, especially when, as in Argelander's method, different comparison stars are given the greatest weight in the comparisons in different parts of the light curve. In general in a series of observations of a short period variable extending over a period of years the errors arising from this source may be considered as accidental. In the present case the original observations, as stated above, have been corrected for this error on the basis of the curves determined. But even here it is readily seen that the effect is not entirely corrected for and that very small relative shifts in different parts of the final light curve may result from the variation of the magnitude of the hour angle error with the brightness of the variable and also from the fact that the observer cannot follow the stars during their motion entirely around their diurnal circles.

The mean observed brightnesses of β Lyrae, corrected for hour angle effect,* are given with their corresponding phases in Table II. The first column contains the phase reckoned from principal minimum; the second, the mean brightness in steps referred to γ Lyrae; the third, the corresponding magnitudes referred to γ Lyrae which is assumed to be 1.22 magnitudes brighter than δ Lyrae. The fourth column gives the number of observations entering into each mean and the fifth the residuals from a smooth mean curve.

* This correction is taken from the lower curves of plate XV.

TABLE II.—NORMAL PLACES.

PHASE	MEAN STEPS	COMPARISON MAGN.	OBSERVATIONS	RESID. MAGN.
0.138	+7.85	+0.958	10	—0.008
0.281	7.70	0.939	10	+0.008
0.427	7.60	0.927	10	+0.011
0.562	7.65	0.933	10	—0.013
0.728	6.95	0.848	10	—0.014
0.926	5.50	0.671	10	+0.001
1.204	3.70	0.451	9	+0.020
1.407	3.07	0.375	10	—0.035
1.547	2.03	0.248	10	+0.004
1.723	1.41	0.172	9	—0.002
2.025	0.51	0.062	10	—0.019
2.225	0.41	0.049	10	+0.003
2.410	0.17	0.021	10	+0.006
2.667	0.41	0.050	10	—0.029
2.917	+0.06	+0.007	10	+0.004
3.154	—0.14	—0.017	11	+0.018
3.363	—0.05	—0.006	11	+0.006
3.611	+0.22	+0.027	10	+0.022
3.897	—0.09	—0.010	11	+0.026
4.264	+0.40	+0.049	10	—0.012
4.460	0.44	0.054	10	—0.001
4.607	0.50	0.061	10	+0.007
4.784	0.64	0.078	10	+0.003
5.003	0.64	0.078	10	+0.027
5.251	1.21	0.148	10	—0.011
5.485	1.51	0.184	10	—0.016
5.774	2.06	0.251	10	—0.036
5.993	1.52	0.185	10	+0.085
6.140	2.32	0.283	10	—0.028
6.293	3.15	0.384	10	±0.000
6.444	3.82	0.466	10	—0.031
6.630	3.36	0.410	10	+0.048
6.847	4.06	0.495	10	—0.043
7.118	2.64	0.322	10	+0.054
7.310	2.47	0.301	10	+0.012
7.437	2.45	0.299	9	+0.037
7.636	1.84	0.224	8	—0.027
7.885	0.86	0.105	10	+0.033
8.102	0.77	0.094	10	+0.005
8.231	0.69	0.084	9	+0.001
8.400	0.37	0.045	10	+0.019

PHASE	MEAN STEPS	COMPARISON MAGN.	OBSERVATIONS	RESID. MAGN.
8.605	0.64	0.078	9	—0.032
8.938	+0.19	+0.023	11	±0.000
9.163	—0.05	—0.006	10	+0.018
9.272	—0.11	—0.013	10	+0.021
9.493	+0.26	+0.032	10	—0.032
9.727	+0.01	+0.002	10	—0.004
9.996	—0.11	—0.014	10	+0.015
10.154	—0.14	—0.017	10	+0.022
10.331	+0.33	+0.040	10	—0.028
10.485	0.45	0.055	10	—0.035
10.690	0.27	0.033	11	+0.004
11.029	0.29	0.035	10	+0.036
11.273	0.63	0.077	11	+0.023
11.508	1.31	0.160	10	—0.020
11.728	1.33	0.162	10	+0.035
11.949	2.47	0.302	10	—0.020
12.156	3.23	0.394	10	+0.020
12.389	5.52	0.674	10	—0.005
12.586	7.36	0.898	9	+0.019
12.826	+7.56	+0.922	9	+0.010

The phases and corresponding magnitudes in this table are plotted in Plate XVI, upper curve. The magnitudes indicated on the margins of this plate apply only to the upper curve and correspond to a magnitude of 3.30 for γ Lyrae, and 4.52 for δ Lyrae.

To exhibit any minor irregularities that may be present in this curve the successive points have been connected throughout. And to determine the bearing of any chance grouping of the observation in forming normal places the original observations have been combined in two other different ways as described above. The new normal places thus found show that the first set represents the observations very satisfactorily though some minor changes in the small features of the curve would result if the parallel mean brightnesses were used.

In Plate XVI a smooth mean curve has been drawn through the observations. Corresponding to this mean curve, the relative phase times and the magnitudes at the principal phases are found in Table III which also contains similar data obtained from the observations of separate years. The phase times refer to principal minimum as computed by Pannekoek's revised formula.

TABLE III.—MAGNITUDES AND RELATIVE TIMES OF PRINCIPAL PHASES.

YEAR	PRINCIPAL MINIMUM PHASE		FIRST MAXIMUM PHASE		SECONDARY MINIMUM PHASE		SECOND MAXIMUM PHASE	
	DAYS	MAG.	DAYS	MAG.	DAYS	MAG.	DAYS	MAG.
1907	0.10	4.29	3.34	3.30	6.67	3.71	9.90	3.32
1908	0.10	4.25	3.35	3.28	6.76	3.68	9.65	3.28
1909	——	4.29	3.55	3.29	6.56	3.84	9.77	3.31
1910	0.16	4.31	3.48	3.30	6.57	3.76	10.17	3.30
1911	0.16	4.28	3.48	3.28	6.65	3.78	10.07	3.30
1912	0.14	4.29	3.50	3.29	6.58	3.77	10.06	3.30
1907–12 Mean	0.13	4.27	3.45	3.29	6.63	3.76	9.94	3.30
Curve	0.16	4.245	3.34	3.300	6.68	3.745	9.69	3.297

From Table III it is evident that the variation in the magnitude at any principal phase in different years is very small; not exceeding 0.06 magnitudes except at the secondary minimum. There is also good agreement with the results in the last line obtained from the final mean curve. In the case of the secondary minimum, variations of magnitude from one year to another amount to 0.16 magn. It should be stated that the accuracy of my observations is least at this phase but it is also interesting to recall that other observers, notably Schmidt, have noted large variations in the magnitude of β Lyrae at the secondary minimum. In my final mean magnitude observations near this phase, these variations are reflected in relatively large irregularities, to which certain minor oscillations in my light curve are attributable.

It is interesting to note that the magnitude differences between β Lyrae and γ Lyrae at the principal phases as determined by the writer agree well with the corresponding results for yellowish green light interpolated from Nordman's observations in blue, yellow and red light. But in general the results of different observers in absolute magnitude are found to differ greatly, largely no doubt because of the differences among the magnitudes assumed for the comparison stars.

It will be noted that the relative times of the principal phases are uncertain. This follows from the nature of the case. That there are no real changes established here is evident from the difference between the phase times determined from

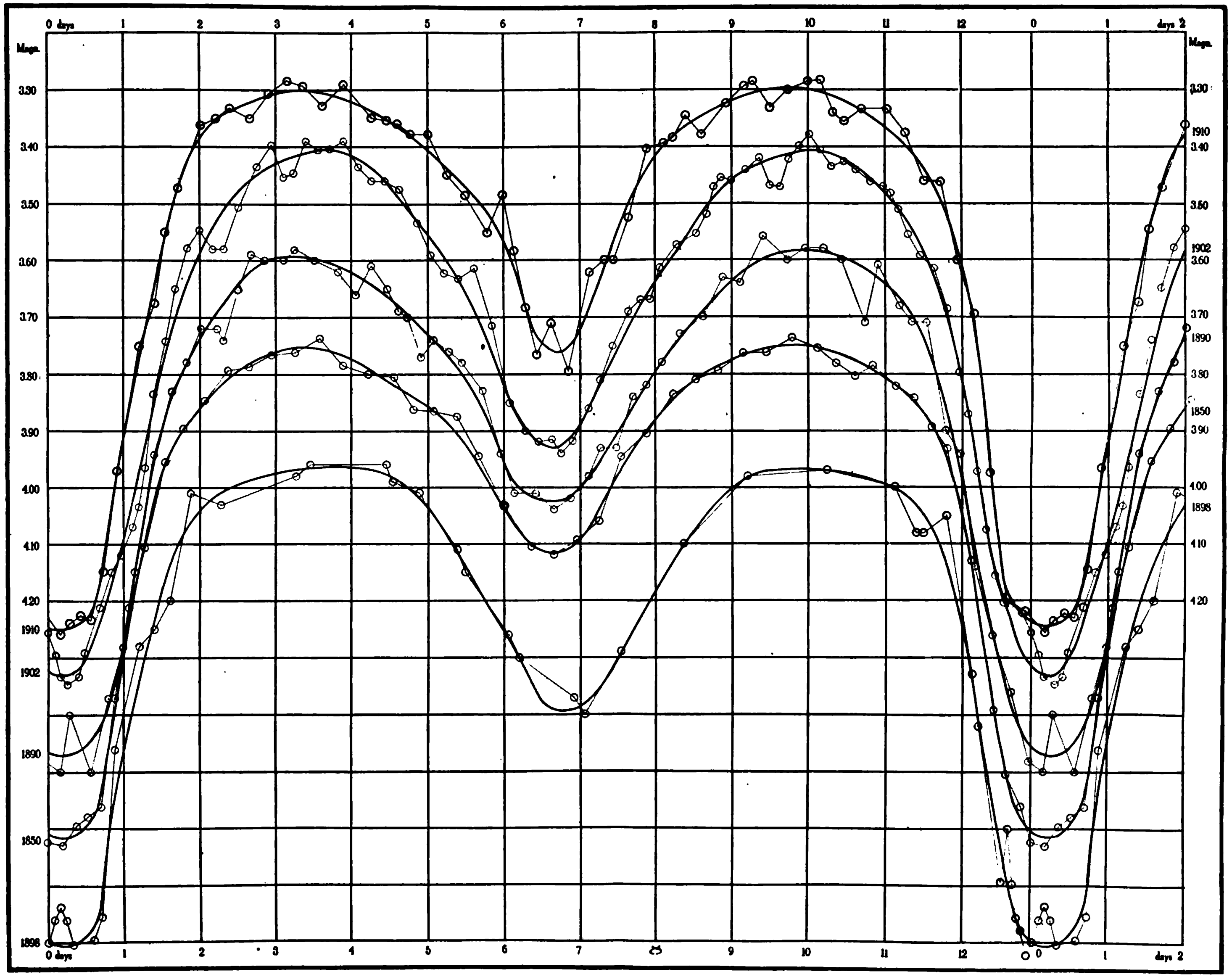

PLATE XVI. LIGHT CURVES OF β LYRAE.

the mean of the yearly values and the same phase times taken from the mean curve.

At the same time a correction to the time of principal minimum as predicted on the basis of Pannekoek's revised formula seems to be well established. For the epoch 1910.0 this correction is $+0.15$ days.

COMPARISON OF RESULTS OF DIFFERENT OBSERVERS.

Probable Errors.

Though the general accuracy of the present results may be estimated well from the curve of Plate XVI, a statement of the probable errors may have some bearing on the reality of the minor irregularities and will serve to furnish an indication of the accuracy of the observing method used here as compared with that of Argelander as usually employed.

The probable error of a single comparison near maximum light in the present series of observations is ± 0.37 steps or ± 0.045 magn. The same quantity near secondary minimum brightness is ± 0.80 steps or ± 0.098 magn.; and near principal minimum it is ± 0.52 steps or ± 0.063 magn. Thus the probable error of a mean of ten estimates may be obtained for any part of the curve. A mean value of the probable error of a normal place for the whole curve obtained from the residuals in Table II is ± 0.13 steps or ± 0.016 magnitudes. In all cases the residuals refer to the smooth curve. They would be somewhat reduced if an irregular curve were used. Argelander's value for the probable error of his single determinations was ± 0.063 magn. and Schönfeld's was ± 0.054 magn., in good agreement with the mean of my values.

It will be seen that the probable error of a single observation in the present series is relatively great when the brightness of the variable is near that of the secondary minimum. This is perhaps partly due to actual irregularities in the variation of β Lyrae at secondary minimum but is probably largely due to the difficulty in estimating large differences in relative brightness. The method of comparison used in this set of observations was adopted, after some experimentation, with the hope that the relative nearness of the comparison stars would compensate for the greater differences between the brightness of the variable and that of one or both of the comparison stars. The results indicate that this is the case on the average and seem to show that for a variable with a range not exceeding seven or eight-tenths of a magnitude this method might give more accordant results than one employing several scattered standards, when two suitable comparison stars near the variable are available.

Principal Phases of the Light Curve.

In a study of the intervals between the principal phases in the light curve of β Lyrae, Pannekoek has discussed all of the more important sets of observations before 1896 in order to test the reality of variations in these intervals suspected by Lindemann.

In Table IV, most of the visual results which have been published to date have been used in the determination of these intervals from principal minimum to the other principal phases. In this table the results at the first epoch are based upon Goodricke's observations only; but those for the second epoch depend upon observations of Argelander, Schönfeld, Oudemans and Schmidt; the third, upon the work of Schmidt, Sawyer, Schur, Schwab, Plassmann, Pannekoek, Glasenapp and Menze. The results of the several individuals in later years are then given. And finally for the interval, 1892-1912, the results of the seven named observers are combined into one mean. Apparently no variations in these intervals are established.

TABLE IV.—INTERVAL BETWEEN PRINCIPAL MINIMUM AND THE OTHER PRINCIPAL PHASES.

EPOCH.	OBSERVER	1ST MAX.		2ND MIN.		2ND MAX.	
1784	Goodricke	3.58	days	6.38	days	9.58	days
1842–1870	Mean	3.12	± 0.013	6.40	± 0.017	9.54	± 0.055
1870–1895	Mean	3.30	± 0.036	6.48	± 0.026	9.73	± 0.055
1892–1902	Beliawsky	3.22		6.59		9.65	
1895–1897	Stratonow	3.07		6.40		9.44	
1896–1905	Markwick	3.62		6.37		9.75	
1897–1900	Wendell	3.40		6.58		9.68	
1898–1906	Luizet	3.34		6.37		9.72	
1902–1908	Lau	3.40		6.46		9.75	
1907–1912	Curtiss	3.18		6.50		9.53	
1892–1912	Mean	3.32	± 0.052	6.47	± 0.028	9.65	± 0.033

The Form of the Mean Light Curve.

In order to facilitate the study of the form of the mean light curve, together with its possible changes, the writer has placed in parallel with his own, in Plate XVI, the results obtained from several representative series of observations corresponding to different epochs.

The earliest curve is that of Argelander. This is derived from 1439 single observations made in the years 1844-1859. Thus the separate means depend upon thirty observations and the average range of phase covered by the observations in any mean is about 0.30 days.

The next curve in order of time (third from the top of the plate) is based upon about 1700 observations made in the years 1877-1897 by Schur, Plassmann, Pannekoek, Glasenapp, Menze and Stratonow. In combining the results of these different observers Stratonow has given his own 634 observations a weight of four; Menze's, a weight of one; and the remaining observations, a weight of two. Thus Stratonow's observations, covering a period of only three years, have a great influence on the final curve. The sixty-one mean magnitudes upon which this curve depends, are each derived from about twenty-eight single observations with a range of phase of about 0.20 days.

Wendell's 221 photometric observations (1897-1900) were used to determine the lower curve of Plate XVI. Except near the principal minimum the plotted points depend upon three or four observations only but near the chief minimum they represent means of from eight to ten single observations. Except for one case, the phase covered by any mean does not exceed 0.15 days.

The more recent curve (1898-1906) of Luizet is the second on Plate XVI. 844 observations are used to form the 84 means corresponding to the plotted points. Using the well known method of overlapping means, twenty observations are combined in each group. Thus each of the original observations is used twice and the average range of phase over which the observations of any mean extend is 0.30 days.

The upper curve represents the writer's observations of the years 1907-1912. The sixty-one plotted points each depend upon ten observations on the average and the average phase interval covered by each is about 0.18 days.

In adjusting these four representative curves to parallelism with my own, the attempt has been made to move them along the time axis in such a way that a considerable section of the curve at the principal minima, and not the absolute minima alone, should be brought into average coincidence. Whenever magnitudes were available the results were platted as furnished by the observer, without alteration of scale, the vertical squares on the diagram representing tenths of a magnitude. Thus the range of the first (the writer's) curve is 0.96 magnitudes; that of the third (Stratonow's) curve, 0.89 magnitudes; and that of the fifth (Wendell's) curve, 0.85 magnitudes. And the vertical scale of the second (Luizet's) and the fourth (Argelander's) curves, for which the results were published in steps, has been made intermediate with respect to the curves between which they are placed on Plate XVI.

The Decrease in Brightness of Secondary Minimum.

The decrease in the brightness of secondary minimum referred to the brightness at maxima has been noted by Luizet who finds the rate of this decrease to be about 0.1 of a magnitude in fifty years. The curves of Plate XVI exhibit this effect and indicate that a progressive sharpening of the curve at this phase is also a possibility, The data bearing on this effect from the two new curves of Plate XVI have been added to those already discussed by Luizet, to form Table V. The scale of each curve has been reduced to that of the third (Stratonow's) curve of the diagram, the total range being 0.89 magn.

TABLE V.—DIFFERENCE IN BRIGHTNESS BETWEEN MAXIMA AND SECONDARY MINIMUM.

Year.	Observer.	Max.—Sec. Min. Magn.
1850	Argelander	—0.37
1863	Schönfeld	0.37
1881	Schur	0.44
1890	Plassmann	0.39
1894	Pannekoek	0.44
1897	Glasenapp	0.50
1897	Stratonow	0.45
1898	Wendell	0.45
1902	Luizet	0.50
1910	Curtiss	—0.43

The Shape of the Maxima.

We may also consider the curves of Plate XVI in connection with Roberts' remark of 1906, "Thus, recent light curves are flatter at maxima than those found by Goodricke and Argelander." As the curve of Goodricke was not very well determined it is perhaps unwise in studying small changes to give much weight to any light curves which antedated the very similar ones of Heis and Argelander the latter of which has never been surpassed in accuracy. In connection with Argelander's curve the several other curves of Plate XVI would seem to throw light upon the point in question.

It is evident that the maxima of Stratonow's curve of 1877 to 1897, based upon the results of six observers are sharper than those of Argelander, and Luizet's curve of 1902 is still sharper. The first maximum of Wendell's curve of 1898 resembles Argelander's very closely but the second maximum of Wendell is sharper than Argelander's. My own curve of 1910 is perhaps flatter than Argelander's at the maxima. I am inclined to ascribe these differences to the tendency, discussed above, to which all observers are probably subject, of underestimating the difference in brightness of two stars of nearly the same magnitude. On comparisons of β with γ Lyrae near the maxima of the variable this source of error has undoubtedly exercised some influence, varying in extent with different observers. The curves of Plate XVI indicate that this may be the case and seem to permit of no definite conclusions as to real variations in flatness of the maxima.

Minor Irregularities.

In drawing the smooth light curve of β Lyrae it seems difficult to avoid introducing a slight subordinate maximum between five and six days after the principal minimum. This was noted by Lindemann and seems to be a well established feature of this curve, though the deviation from a smooth curve does not exceed two or three hundredths of a magnitude.

In addition to this small irregularity in the light curve of this star, Lindemann and Pannekoek have suspected the physical reality of other excursions of the observed brightness of this variable above and below a smooth curve. Stratonow considers ten of these irregularities certain and Luizet finds nine minor oscillations of the light curve to be well established, three others fairly certain and a thirteenth suspected. Three of these he finds persisting in the observations from 1784 to 1906. Six others were observed over nearly a hundred years.

The character of the oscillations in question is well shown in each of the curves in Plate XVI. Since the period of these minor oscillations is roughly of the order of one day it will be noted that in one respect the curves of Stratonow, Wendell, and the writer should serve to bring out these irregularities best, for the range of phase covered by the observations in each mean is smaller than in the cases of the other curves. But all the curves of Plate II are of importance in this connection.

It is therefore interesting to note that in Argelander's curve, which is probably the strongest known, the extent of these excursions is the least. It is also noteworthy that the combination of Stratonow's own observations with those of other observers reduced the average amplitude of the minor oscillations in his curve and probably would have done so to a greater extent if the observations of the others had been given the same weight as his own. It would seem to be the case that, if the curves of Plate XVI were combined into one mean curve, few if any of the minor oscillations would survive. In general there seems to be no established synchronism in the occurrence of these oscillations in different curves.

On the other hand there seem to be some resemblances between the minor oscillations of different curves, which are hard to explain as accidental. Thus, beginning at the minor maximum of phase, 10 hours, which is found well defined in the curves of Luizet and the writer, and following these two curves back to the first maximum it will be seen that very similar irregularities occur in both curves, not in synchronism, but *in an interesting symmetrical relation with respect to the secondary minimum.* Other resemblances between different curves raise interesting questions. Probably some resemblances are acci-

dental. Possibly some are real. But it would seem that the whole question must await the evidence of photometric observations or perhaps of visual comparisons secured through the coöperation of a number of observers.

THE REALITY OF CHANGES IN THE LIGHT CURVE.

The opinion of some observers seems to be that while the minor irregularities persist for long periods of years, there are well marked changes in the form of the general light curve from one epoch to another. These changes, both in the maxima and minima, have been discussed above and may be seen at a glance in Plate XVI. They are usually small in extent. In most cases they could not be established through the visual observations of one observer in two years. They seem reliable only when based upon long means. In view of the personal, systematic errors which enter into these means it would seem that the reality of many of the observed changes in the light curve of β Lyrae may not be regarded as established. And suspected changes in the elements of the system derived from the light curve are to be announced with caution. It seems not improbable, as Keeler found in the case of spectroscopic observations of this star, that more refined methods will show that the light variation of β Lyrae in the thirteen-day period is repeated with less irregularity than present results might lead us to think.

SUMMARY.

In the present paper the errors affecting visual light comparisons of stars are first discussed. And a method, employing but two comparison stars, is adopted in the hope that some of these errors may be varied if not controlled.

Six hundred and twelve observations made by this method are given in detail and are reduced, for the determination of the light curve, in a manner calculated to bring out and partly eliminate the effect upon the apparent relative brightness of two stars due to their relative position in the sky.

The light curve of β Lyrae for each year from 1907-1912 is determined and also a mean curve for this whole period is drawn. A correction, at the epoch, 1910.0, of + 0.15 days is found for the time of principal minimum as predicted on the basis of Pannekoek's revised formula.

Among the writer's own curves in different years and among the writer's curve and those of other observers there are seen to be few if any established physically real differences. The relative intervals between the principal phases can not be said to change. The range of brightness from the maxima to the principal minimum is difficult to establish; but if this be considered constant for different observers the relative brightness at secondary minimum appears to be decreasing. A change in the form of the maxima involving increase in flatness in recent curves does not seem to be supported by the evidence collected here.

There seems to be some evidence of the reality of one persistent minor irregularity in the curve of β Lyrae. The reality of a number of others which have been suspected, is made to appear uncertain. The physical reality of many of the observed changes in the light curve of β Lyrae is questioned.

As the method of observation employed here by the writer seems to yield results comparable in accuracy with those obtained by other applications of Argelander's method, the work is being extended to other stars in the hope that information may be gained with reference to personal, systematic errors, which may help in the determination of the visual light curves of these interesting objects.

1913.

SOME POSSIBLE CHARACTERISTICS OF CEPHEID VARIABLE STARS*

By RALPH H. CURTISS

Though the list of announced characteristics of Cepheid variables is a long one, no satisfactory solution of the problem of the light variations of these stars seems to be in sight. Further information is needed in connection with the extension of old discussions, and new relations bearing upon the problem of Cepheid light variation are of great interest.

DISTRIBUTION BY PERIODS.

Attention has been called by Campbell and others to the relative preponderance of Cepheid stars with periods between certain limits. Campbell's deductions from fifty-three cases are well borne out by the ninety-three stars of this class included in the latest list of Luizet. In this list[1] it is possible that certain ellipsoidal variables have been included, but for the present it seems difficult or impossible to exclude them and their influence on the result will be small if not negligible. Probably some antalgol stars are also found here, especially among those with periods less than one day. The intentional inclusion of antalgol stars may prove desirable when more is known about them. SV Geminorum is to be excluded as an Algol star.

In this list compiled by Luizet there are thirteen stars with periods less than half a day. Eight have periods between 0.5 days and one day; two, between one day and two days; two, between two and three days; five, between three and four days; eight, between four and five days; seven, between five and six days; nine, between six and seven days; and eight, between seven and eight days. At this point the number of stars decreases sharply with increasing period. Only two are known with periods between nine and ten days. Above this limit this relative scarcity of known cases becomes more marked up to periods of twenty days from which point the Cepheids known are thinly distributed up to the present limit of 41.3 days. Considerably more than one-third of all known Cepheid variables have light periods between three and eight days. Nearly one-quarter of all Cepheid variables have periods less than a day.

These relations are shown graphically in the curve of Plate XVII, in which the relative number of stars with periods within a limit of one day are plotted with appropriate mean values of the period as abscissae. The determination of the points so plotted calls for certain rather arbitrary decisions such as are ordinarily met with in forming normal places but the form of the curve is well substantiated.

The curve of Plate XVII would seem to indicate that these stars may be divided into two groups: one with a preference for periods of four to eight days but possibly including variables with periods up to 100 days; the other, with periods less than two days. However the apparent division between these groups may not be a real one, for scarcity of known Cepheid variables with periods of one to three days may be due to difficulties attending the discovery of these stars because of their smaller magnitude range as shown on Plate XVIII.

PERIOD AND MAGNITUDE RANGE.

For the study of the relation between variation period and magnitude range in Cepheid variables the available material seems fairly adequate. And for the purpose I have adopted Luizet's list of ninety-three stars cited above. The data derived from Luizet's list are found in Table I. In this study the stars in this list were first arranged in order of periods. And for

* Note added Feb. 10, 1915. In order to avoid further delay in the publication of this paper, which has been in press for a long time, no discussion or revision is attempted on the basis of contributions which have come to hand since August 1, 1913, when the paper was completed.

[1] *Luizet. Annales de L'Universite de Lyon. Nouvelle serie. I, 33 pp. 3-5.*

groups of stars with periods ranging between selected limits, direct means of the periods and corresponding magnitude ranges were taken. These average periods are found in the first column of Table I, and in the second column appear the corresponding limits within which lie the periods entering into each mean. The mean magnitude range and its probable error are found in the third and fourth columns of this table. The data of the first and third columns of Table I are plotted in Plate XVIII with periods as abscissae.

In view of the determinate character of the plotted points there seems to be little question as to the physical reality of the variation indicated. Possibly the small indicated increase in magnitude range with increasing periods up to 0.5 days is not real. But the rapid decrease of magnitude range with increasing periods from 0.5 days to 2.0 days seems well established and the rapid increase of magnitude range for periods increasing from 3.0 to 6.0 days is hardly to be questioned. From this point on, the average magnitude range increases by approximately 0.1 magnitudes for each ten days' increase of the period of light variation but with a tendency toward a decrease, for greater periods, in the ratio of change in magnitude range to increase in period.

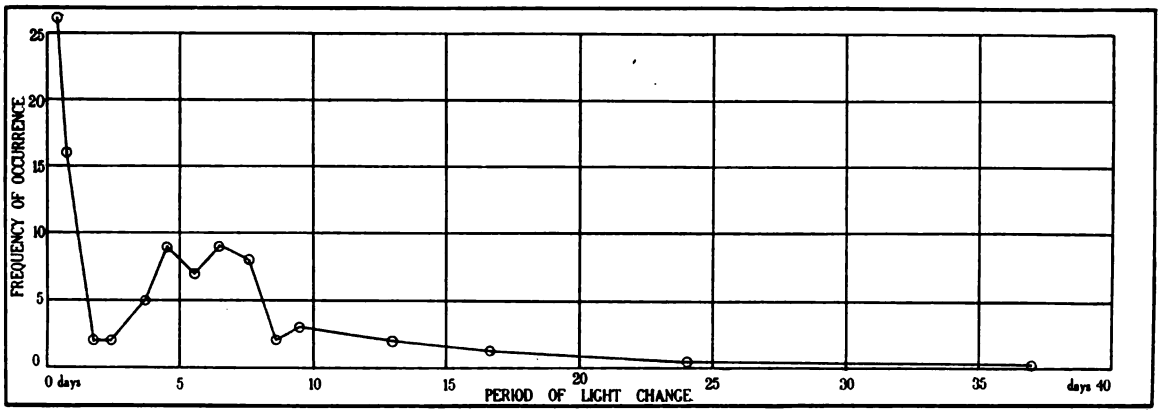

PLATE XVII. GRAPHICAL REPRESENTATION OF THE RELATION BETWEEN FREQUENCY OF OCCURRENCE AND PERIOD IN CEPHEID VARIABLES.

TABLE I. PERIOD AND MAGNITUDE RANGE IN CEPHEID VARIABLES.

MEAN PERIOD days	LIMITS OF PERIOD days days	MAGNITUDE RANGE magn.	PROBABLE ERROR magn.	NO. OF STARS
0.31	0.00 — 0.44	0.86	±0.09	7
0.47	0.45 — 0.50	0.97	0.12	6
0.72	0.50 — 1.00	0.82	0.05	8
2.08	1.00 — 3.00	0.65	0.10	4
3.70	3.00 — 4.00	0.70	0.08	5
4.51	4.00 — 5.00	0.96	0.05	9
5.55	5.00 — 6.00	1.07	0.15	7
6.44	6.00 — 7.00	1.06	0.09	9
7.63	7.00 — 8.00	1.06	0.11	8
8.94	8.00 — 10.00	1.08	0.15	6
12.98	10.00 — 15.00	1.14	0.07	10
16.57	15.00 — 20.00	1.18	0.09	6
29.	20.00 — 41.31	1.26	0.07	8

It should be noted also that the use of the photometric data by Pickering in Volume 46 of the *Harvard Annals* would introduce a second minimum in the curve corresponding to periods between seven and eight days. This is attributable to a tendency toward relatively smaller range for the average case as derived from Pickering's results. Though the accuracy of Pickering's values probably exceeds that of the data relative to magnitude range in Luizet's list, it has seemed best for the sake of homogeneity to exclude the Harvard results.

It would seem that the curve of Plate XVIII must depend upon several factors. For stars with periods in the neighborhood of six days the magnitude range is about 1.05. For longer periods the increase in the corresponding magnitude range may be due in part to the diminished

chance of discovery of a variable star of smaller range as the period increases. As the period decreases to two days the magnitude range decreases sharply, possibly because of a greater relative brightness of the secondary or fainter component of the system, the variations of which may be opposite in phase to those of the primary. Finally as the period decreases from two days, the magnitude range increases rapidly possibly because of effects associated with close approach and rapid rotation, such as varying presentation of ellipsoidal bodies.

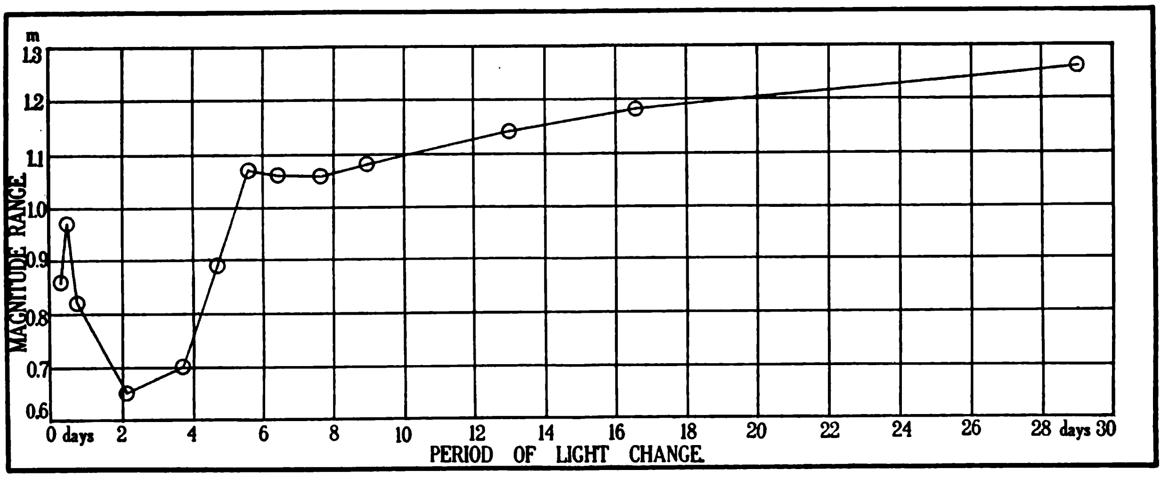

PLATE XVIII. THE VARIATION OF MAGNITUDE RANGE WITH PERIOD IN CEPHEID VARIABLES.

But throughout the whole range of periods covered by this curve, the effect of the discovery factor must not be overlooked. Very probably future discoveries of variables of this class, employing improved methods of search, will modify or perhaps transform conclusions drawn from the data now available; and this is especially true of deductions based upon magnitude range.

PERIOD AND VELOCITY RANGE.

In considering the element K, the velocity half-range, in relation to the period, attention should be directed at once to the possibility of predicting the average value of this element on the basis of the curve of Plate XVIII in combination with Ludendorff's relation,[2] $K = 23.7\,A$, where A denotes the magnitude range. But in the case of stars which have been observed spectroscopically this prediction is not verified, for the magnitude range of these stars differs greatly from the average values for all Cepheid stars, particularly if Pickering's photometric results are employed. This departure from the average curve may be connected with the greater relative brightness of these stars though there seems to be no clear evidence to support this view. More probably these apparent discrepancies are of a purely accidental type. For the *average* Cepheid variable, if K is directly proportional to the magnitude range on the average, as the facts for the brighter stars of this class seem to indicate, the variation of K with the period will follow that of the curve of Plate XVIII. As the period increases from two days the value of K increases rapidly at first and then more gradually, while the scale of the corresponding projected orbits depending on the product of K and P becomes relatively great. For periods less then two days K increases rapidly with decreasing periods down to about 0.5 days but there is no indication of further increase for periods less than this. Thus it would seem that for several stars with periods of a few hours the values of the semi-axes major are surprisingly small unless the inclination of the orbital planes be very small; and thus there is reason to think that the relation between velocity and light amplitude in Cepheid variables is not so simple as that expressed by the

[2] *Ast. Nach.*, Vol. 193, p. 301.

simple linear equation deduced by Ludendorff from stars with periods all greater than 3.7 days. It is possible, as suggested also by the distribution of these stars by periods, that those stars in Luizet's list with periods less than one day, form a group for which the causes of light variation differ from those which are present in the case of stars with periods greater than three days.

Whatever connection may be indicated between magnitude and velocity range in Cepheid variables it seems desirable to examine the available data for a direct relation between the velocity range and the period for these stars. If we plot values of K with periods as abscissae, a straight line with downward slope would seem to represent the plotted points as well as any curve. Thus the expression,

$$K = -0.93\,P + 24,$$

in which K and P are measured in kilometers and days respectively, is satisfied fairly well by the known values of these quantities. However, such an expression leads to impossible results for large values of P. Apparently the relation between P and K for these stars is better represented by the equation,

$$P = 2000/K^2$$

and the results in Table II are based on this expression. In this table, the difference between the observed velocity range, Ko, and that computed by the above formula, Kc, is exhibited for each star.

If this relation be assumed between P and K, the expression connecting P and $a \sin i$ takes the form,

$$a^2 \sin^2 i = (6.15 \times 10^8)\,(1 - e^2)\,P.$$

Values of the projected semi-axis major computed from this formula are compared with the corresponding observed quantities in Table II for each star considered.

There seems to be some evidence in favor of the physical reality of these relations. But the data are few and so far as available results go, Polaris, X Cygni and l Carinae do not conform to the expression above. Possibly these relations are well enough defined to justify consideration when further data become available. They are advanced here only tentatively to present whatever evidence they may furnish.

MAXIMUM LIGHT AND MAXIMUM VELOCITY OF APPROACH IN CONNECTION WITH VELOCITY OF SYSTEM.

It is well known that there is a synchronism, more or less close, between maximum light and maximum velocity of approach in all Cepheid systems so far investigated. And convincing theories have been advanced which account for this condition on the hypothesis that there exists in each of these systems, a resisting medium which enhances the relative brightness of that side of the star which faces the direction of orbital motion. In this connection the suggestion arises that in the case of some systems (more probably in the case of a rapidly receding system) the primary is at no time moving toward the sun relatively to a resisting medium through which the system may be proceeding. In this event the periodic light variations of such a system may be dependent upon causes which are most effec-

TABLE II.

STAR	P days	Kc km.	Ko km.	$Ko-Kc$ km.	$(a \sin i)c$ km.	$(a \sin i)o$ km.	$(a \sin i)o-(a \sin i)c$ km.
RT Aurigae	3.73	23	17	−6	1,110,000	860,000	−250,000
SU Cygni	3.84	23	25	+2	1,180,000	1,350,000	+170,000
T Vulpeculae	4.44	21	18	−3	1,170,000	970,000	−200,000
δ Cephei	5.37	19	20	+1	1,330,000	1,370,000	+ 40,000
Y Sagittarii	5.77	19	19	±0	1,460,000	1,485,000	+ 25,000
X Sagittarii	7.01	17	15	−2	1,490,000	1,330,000	−160,000
U Aquilae	7.02	17	13±	−4	....	....	....
η Aquilae	7.18	17	20	+3	1,440,000	1,770,000	+330,000
W Sagittarii	7.60	16	19	+3	1,580,000	1,930,000	+350,000
S Sagittae	8.38	15	19	+4	1,670,000	2,000,000	+330,000
ζ Geminorum	10.15	14	13	−1	1,910,000	1,800,000	−110,000
Y Ophiuchi	17.12	11	8	−3	2,530,000	2,000,000	−530,000

tive on the side of the primary which is directed away from the earth. Possibly under these circumstances the correspondence between the velocity and light phases will not be so well marked on the average as in the case of a system approaching the observer.

To test this possibility, the data are again meager. In Table III, the Cepheid stars for which this datum is known are assembled in the order of increasing values of the velocity of recession of the system relative to Campbell's system of brighter stars. In the third column of the table, in parallel with these velocities, is given the corresponding quantity, time of maximum light, M_l, minus time of maximum velocity of approach, M_a, in terms of the corresponding light and velocity period. While the evidence is weak there is some indication of a tendency toward an increase in the absolute value of $M_l - M_a$ with increasing velocity of recession. The average values at the foot of the table indicate that this tendency is not associated with the elements, P, e, and the magnitude range.

TABLE III.

COMPARISON OF VELOCITY OF SYSTEMS WITH CORRESPONDING DIFFERENCES BETWEEN LIGHT AND VELOCITY EPOCHS IN CEPHEID VARIABLES.

STARS	VELOCITY OF SYSTEM	$M_l - M_a$	MAGN. RANGE	P DAYS	E
W Sagittarii	—19km.	—0.01P			
SU Cygni	—16	+0.05			
ζ Geminorum	— 7	—0.02			
X Sagittarii	— 4	—0.04			
δ Cephei	var.	+0.04			
η Aquilae	± 0	0.0			
S Sagittae	+ 4	—0.02			
Y Ophiuchi	+10	—0.10			
RT Aurigae	+12	+0.05			
T Vulpeculae	+14	+0.07			
Y Sagittarii	+16	+0.14			
Approaching Stars	—11	0.030P	0.75	7.1	0.29
Receding Stars	+11km.	0.076P	0.65	7.9	0.28

POSITION OF PERIASTRON.

In several papers in which the orbital elements of the Cepheid variable stars have been assembled, the fact has been evident that the values of the angular distance of periastron passage from receding node exhibit a preference for the first and second quadrants. From our knowledge of these stars, such a tendency is to be expected. For, if the well known tendency toward coincidence of the epochs of maximum light and maximum velocity of approach and also of the epochs of minimum light and minimum velocity of approach, in the Cepheid stars, studied spectroscopically, is to exist in combination with the well known tendency toward rapid increase and slow decrease of brightness in these stars, it is obvious that there must also obtain in these variables a tendency toward values of ω between 0° and 180°, or in other words, a tendency for the occurrence of periastron passage in the descending branch of the velocity curve. This tendency is brought out in Table IV in which the Cepheid stars are arranged in order of increasing values of the element ω. (SU Cygni is not included in Table IV because of an apparent error in the published value of ω for this star.)

TABLE IV. VALUES OF ANGULAR DISTANCE OF PERIASTRON FROM RECEDING NODE IN CEPHEID VARIABLES.

ζ Geminorum	—27°
Y Sagittarii	+ 32
η Aquilae	69
S Sagittae	70
W Sagittarii	70
δ Cephei	83
RT Aurigae	95
X Sagittarii	94
T Vulpeculae	111
Y Ophiuchi	+202

Not only do these values tend to group themselves in the first two quadrants but eight out of ten fall within limits of 40° of the value of 71°.

ζ Geminorum is a notable exception both to the tendency shown in Table IV and to the marked tendency toward asymmetry in the light curve. Y Ophiuchi presents an interesting exception in that its light curve is asymmetrical in conformity with the general tendency whereas its periastron passage occurs on the ascending branch of the velocity curve. Under these circumstances discrepancies are to be expected between the epochs of the light and velocity curves of this star. On the basis of the velocity curve computed by Miss

Udick[3] and the light curve of Pickering there is a close correspondence between the epochs of minimum light and maximum velocity of recession but a discrepancy of 1.7 days or one tenth of the period is found between the instants of maximum light and minimum velocity.

IRREGULARITIES IN THE VELOCITY CURVES.

The study of the velocity curves of a large number of spectroscopic binary stars has yielded results which support the conclusion that real departures from a form corresponding to elliptic motion in these curves, not due to blending of lines, seldom attain to an appreciable magnitude, even in the case of very close pairs. However in the case of the Cepheid variables which have been studied with the spectrograph there are three conditions which are thought to obtain in the average case and which in *some* cases would seem to be competent to produce recognizable distortions in the velocity curves of these stars. Thus, there is evidence to show that the principal component, whose spectrum is observed, is of many times the volume of our sun. Possibly one hemisphere of this primary is about twice as bright on the average as the other. Probably this star rotates in a period not far different from 7.5 days, the orbital period of the average pair. If these three conditions are suitably combined in any one case it would seem probable that irregularities in the velocity curve of such a star might be observed.

The evidence pointing toward the probability of the existence of these three conditions in Cepheid stars has been discussed more or less by several investigators. On the basis of the magnitudes and observed proper motions of six Cepheid variables Ludendorff has pointed out the strong probability that the average absolute brightness of these stars even at minimum light is considerably greater than that of our sun. Making only the most reasonable assumptions he shows that these stars on the average are probably about fifty times brighter at light minimum than is the sun.[4] Since the spectrum of these stars is invariably of solar type, it seems probable that the surface brightness of these bodies is not far different from that of our sun. It therefore may be considered as probable that the surface of the average Cepheid star of this group is considerably more extensive than the sun's surface.

Suggested conclusions with reference to an effective difference between the apparent brightnesses of opposite hemispheres of a Cepheid star are based upon studies of the light and velocity variations. As stated above, a promising theory, advanced to account for the light variation of Cepheid variables, is based on the assumption that the hemisphere of the primary which faces the direction of orbital motion is rendered more luminous relatively to the following half of the star by the action of a resisting medium. There seems to be much to recommend this theory as first proposed by the writer in connection with studies of W Sagittarii. Whether the assumed resisting medium produces a relative difference in the brightness of the advancing and following faces of a moving star by meteoric bombardment, as suggested by Loud, or by displacement of the atmosphere, as suggested by Duncan, or whether *both* effects are present, it would seem that a variation of the kind observed in Cepheid variables might result.

If it be the brighter half of the primary which is exposed to the observer's view at the time of maximum light and maximum velocity of approach, and if it be the fainter half which is seen at the time of minimum light and of minimum velocity of approach, a basis is furnished for the estimation of the relative brightness of these two unequally luminous regions of the star's surface, since the corresponding range in apparent brightness is known. Now the range of magnitude for the average Cepheid variable in Table III is about 0.7; and if this be considered a measure of the difference in effective brightness of the brighter and darker hemispheres of each star on the average, it would seem that, in the minimum, the brighter half of the primary's surface must emit about twice as much light as the fainter hemisphere.

As to the probable value of the period of rotation of a component of a Cepheid pair there would

[3] *Publications of the Allegheny Observatory*, Vol. II, p. 151.

[4] See also Russell's paper, *Science*, Vol. 37, p. 652.

seem to be some room for speculation, particularly in view of the high average eccentricity observed in these systems. Although the mass of the secondary is probably relatively small, it will be considered that the operation of tidal friction in these systems would tend to place or hold the rotational and orbital periods in coincidence or commensurability, opposing the tendency toward rotational acceleration due to contraction. At least it seems probable that the rotational and orbital periods will be of the same order of magnitude in any Cepheid star.

If, in application of the above conclusions, we make the apparently conservative assumption that the area of the surface of the primary of the average Cepheid variable star is four times that of our sun, the period of rotation being seven days, it follows that the rotational velocity of an equatorial point of such a star will take the large value of fourteen kilometers per second. Accordingly, if the distribution of luminosity over the surface of such a star be such as has been assumed above as probable, it would seem that cases with velocity curves showing irregularities of appreciable magnitude might occur among Cepheid variables.

However, it must be kept in mind that the ease of detection of a secondary curve superposed upon a velocity curve corresponding to orbital motion in a closed conic section depends not only on the magnitude of the irregularity but also upon its period and position with reference to the primary and upon the form of the two curves combined.[5] Thus, if we superpose a curve corresponding to circular motion upon another of the same period, the result is a circular velocity curve whatever the relative phases of the original curves may be. Consider an elliptic velocity curve corresponding to the orbital elements which we may consider normal to the average Cepheid variable: $e = 0.30$, $\omega = 70°$, $K = 17$ km. If we superpose upon this a sine curve of the same period, representing the velocity curve due to the rotation of a star with unequally bright hemispheres and expressed by equation,

$$V = -6 \sin (M + \omega) \text{ kilometers,}$$

(the simplest assumption and perhaps a reasonable one so far as the amplitude is concerned) there results a curve which is satisfied throughout its length within a fraction of a kilometer by the elements, $e = 0.28$, $\omega = 110°.6$, and $K = 18.0$ km. If, then, the secondary curve produced by rotation in any system is a simple sine curve, with a period equal to the orbital period, its presence will not be recognized under these circumstances even though it may alter quite appreciably the elements derived in the usual manner from the velocity curve.

However it is probable that no one will maintain that the rotational curves of a Cepheid varible under the conditions here supposed would usually be simple regular figures like a sine curve with the period identical with the orbital period. A consideration of the librations and varying orbital velocity in the Cepheid systems of marked eccentricity would render this view untenable. Accordingly, if the conditions assumed above are present in the average Cepheid system it would seem that some cases of irregularity in their velocity curves might be found.

There are ten Cepheid variables including Polaris of which the velocity curves are fairly well determined. Of these, two (those of ζ Geminorum and W Sagittarii) are known to be irregular; one (that of RT Aurigae) shows strong evidence of irregularity; and two (those of η Aquilae and Y Ophiuchi) have been suspected of irregularity. In addition, the velocity curve of S Sagittae has given evidence of departure from elliptic form. Probably this proportion of curves, irregular or suspected of irregularity, is such as we might expect in view of the points discussed above.

Although the detection of a secondary sine curve of the same period as the principal curve may not be possible, it will nevertheless be interesting to examine the irregular velocity curves of two of these stars, ζ Geminorum and W Sagittarii, in an avowedly preliminary way, to determine the possible character of the secondary

[5] See Russell's paper *Astronomical Journal*, Vol XV, p. 252.

curve, *considered as due to rotation,* under various assumptions as to its period and the elements of the principal curve, and to consider the secondary curves so found in connection with the rotation theory here proposed.

The irregularity of the velocity curve of ζ Geminorum was established by Campbell, whose excellent observations, extending from 1898, November 11, to 1900, February 11, indicated that this irregularity was not a rapidly changing phenomenon. He considered the period of the superposed curve to be one-third that of the principal on the average, but on that basis did not succeed in determining a secondary curve of closely similar amplitude, form and period throughout the three complete excursions comprised in one period of the principal curve. The observations are plotted in the lower figure of Plate XIX.

The irregularity of the velocity curve of W Sagittarii was discovered by the writer. The observations, which were made for the most part in one year, were not sufficient to determine the details of the curve with great accuracy, but the general form, including the irregularity, was well established. The secondary or superposed curve was considered to be a sine curve with an amplitude of 4.2 km. at the crest and 5.5 km. at the trough with a period one-half that of the primary curve. Subsequently a striking resemblance was noted by the writer between the velocity curve of this star and the photometric light curves which had then been published, as determined by E. C. Pickering a few years before.

At first sight there seems to be little resemblance between the velocity curves of ζ Geminorum and W Sagittarii. So far as the writer knows, none has been pointed out. But if either curve be reversed, as the reader may do mentally in connection with Plate XIX, the form of the two curves becomes strikingly similar. Indeed the conclusion is at once suggested that a similar though reversible process of periodic change is revealed in each system. But, though this may be the case, further examination has not indicated that these curves illustrate direct and reversed aspects of exactly the same cyclical change.

EXPERIMENTAL CURVES.

Considering first the case of ζ Geminorum (the heavy line of the lower figure of Plate XIX), on the assumption that the orbital and secondary periods are closely identical, a secondary oscillation, one of the many possible, is at once suggested by the form of the velocity curve. But in order to test the possible application of a rotational theory, the selection of the principal curve may be influenced especially by three considerations: that the secondary oscillation should be regular, that the cross points of principal and secondary curves should be roughly one-half period apart, and that the displacement of the velocity curve with reference to the orbital curve should be negative on the descending branch and positive on the ascending branch of the latter curve. One set of elements is given in Table V.

TABLE V.—ELEMENTS OF THE VELOCITY CURVE OF ζ GEMINORUM.

	PRIMARY CURVE	SECONDARY CURVE
P	10.154 days	10.154 days
ω	295.°7	——
e	0.11	——
T	8.42 days	——
A	+26.0 km.	+8.5±km.
B	−10.0 km.	−6.5±km.
V_0	+7.1 km.	——

A glance at the curve of short dashes in the lower figure of Plate XIX will disclose the character of the selected secondary oscillation. It will be seen that it is little if any more closely like a circular velocity curve than is Campbell's third-period oscillation. Further the deviations of this secondary from a circular velocity curve are about as great at some points as the deviation of the velocity curve from a mean elliptical curve. Evidently this empirical analysis of the velocity curve does not lead to a simple secondary oscillation and from that point of view does not simplify the problem. It does suggest the presence in the system of a large effect due to rotation which, if established, might explain the irregularities so far unaccounted for. But the objection remains that a large irregularity is assumed in order to explain one apparently much

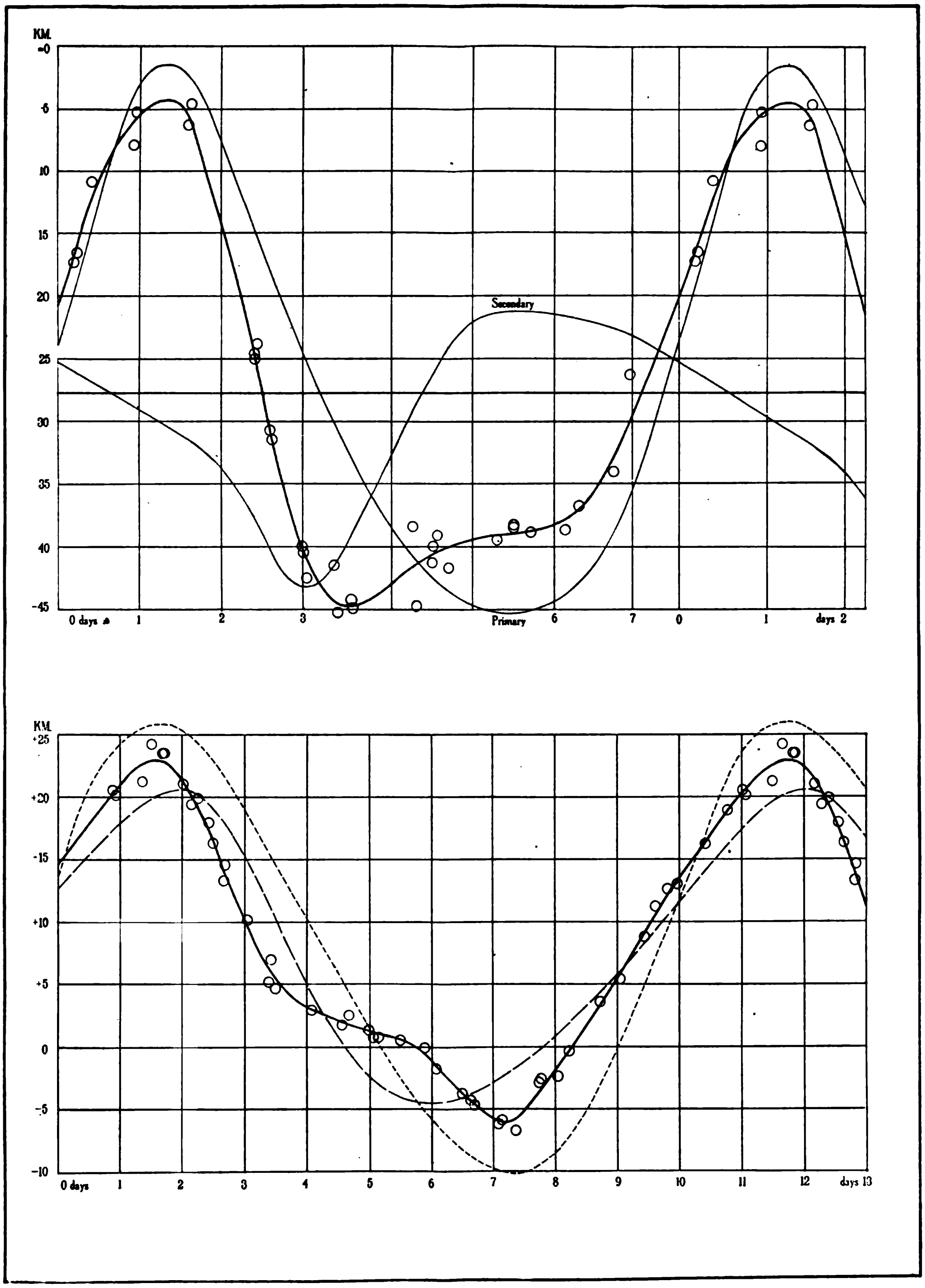

PLATE XIX.

UPPER FIGURE. SUGGESTED ORBITAL AND ROTATIONAL CURVES OF W SAGITTARII. (OBSERVATIONS BY CURTISS.)

LOWER FIGURE. EXPERIMENTAL ORBITAL AND ROTATIONAL CURVES OF ZETA GEMINORUM. (OBSERVATIONS BY CAMPBELL.)

smaller and by some this will be considered unfavorable to the reality of the curves drawn. So far as this combination of curves goes, as well as other combinations which have been considered by the writer, there seems to be nothing pointing definitely to the action of rotation in a whole period as producing the irregularities in the velocity curve of ζ Geminorum.

Though deviations of the secondary oscillation from a sine curve are not to be considered fatal to a rotational hypothesis there are certain conditions which such an oscillation might be supposed to satisfy. If the primary curve is to be considered as corresponding to the true elliptical motion of the primary star, the excursions of the actual velocity curve with reference to this primary being attributed to the rotation of this body, assumed to be unequally bright, in a period equal to the orbital period, the cross points of the two curves should represent instants when the brighter hemisphere is presented to or away from the observer. Apparently, on this basis, as is evident from a consideration of the relative positions of the orbital and rotational curves, the cross-point at phase, 2.9 days, should correspond to the instant of presentation of the bright area of the star's surface to the observer; and the cross-point at 8.2 days, to the instant of presentation of the darker area. Apparently these velocity phases ought to correspond to the epochs of maximum and minimum light. But the first precedes the light maximum by about one-fifth of the orbital period; and the second, the light minimum by a like interval. An explanation for this discrepancy is suggested if we note that the first cross point occurs at apastron and the second at periastron. Though the brighter area of the star may be presented to the observer at the instant corresponding to the first cross point, the brightening of the star's surface due to greater orbital velocity after apastron passage may, for a time, overcome the dimming due to the turning away of the brighter area by rotation. Similar considerations may be advanced to account for the discrepancy in connection with the second cross point.

It might also be expected that the cross points of the principal and secondary curves would synchronize more closely with the epochs of orbital maximum and minimum of velocity. Only part of this discrepancy is explained as the result of simple librations. To account for the rest we may make various assumptions: e. g., that part of the brightening effect of the resisting medium is of a semi-permanent nature, and that the period of rotation is a very little shorter than the orbital period.

Considering the velocity curves of W Sagittarii on the same basis as above, the rotational and orbital periods being assumed closely identical, primary and secondary curves have been determined as represented by the elements in Table VI. In this case there seems to be no connection between the curves derived and the rotation theory proposed above unless the direction of rotation be opposite to that of orbital revolution; and such a condition appears so improbable that the corresponding curves have not been shown.

TABLE VI.—ELEMENTS OF W SAGITTARII.

	PRIMARY CURVE	SECONDARY CURVE
P	7.595 days	7.595 days
e	0.26	——
ω	72.°7	——
T	1.15 days	——
A	+ 1.0 km.	+10 km.
B	—53.6 km.	—10 km.
V_0	—28.4 km.	

But other interpretations of the velocity curve of W Sagittarii are possible if we adopt a secondary oscillation, differing considerably from a sine curve both as to form and equality of positive and negative amplitude, but showing no marked irregularities, and conforming well to certain requirements of a rotation theory. The elements of one set of curves are given in Table VII, and the curves themselves are shown in the upper figure of Plate XIX.

TABLE VII.—SECOND ELEMENTS OF W SAGITTARII.

	PRIMARY CURVE	SECONDARY CURVE
P	7.595 days	7.595 days
e	0.21	——
ω	333.°0	
T	4.71 days	
A	— 1.2 km.	+ 6.5 km.
B	—45.7 km.	—15.5 km.
V_0	—27.8 km.	

In selecting this primary curve three considerations have been kept particularly in view; that there should be one maximum and one minimum in a complete oscillation of the secondary curve, that the cross points of the primary and secondary curves should be very nearly one half-period apart, and that the displacement of the velocity curve with reference to the orbital curve should be negative on the descending branch and positive on the ascending branch of the latter curve—all in accordance with the simplest application of a rotation theory. The amplitude and form of the secondary oscillation (shown clearly in the upper figure of Plate XIX) result from the application of these conditions with an added preference for smaller amplitudes.

In this case it will be noted that the cross points corresponding to presentment of the darker area to the earth precedes the light minimum by one-tenth of the period; and the cross point corresponding to presentment of the brighter area to the observer follows the light maximum by a slightly greater interval. But periastron occurs immediately ($0.035P$) after the first cross point; and apastron shortly ($0.040P$) after the second. These last facts suggest that the increasing faintness of the following side of the star in the neighborhood of periastron passage modifies the rotational effect and retards the occurrence of minimum light, and that the decreasing brightness of the preceding face as the velocity approaches its minimum at apastron leads to the occurrence of maximum light shortly before the brighter area is most nearly presented to the observer.

The greater amplitude of the minimum of the secondary curve as compared with that of the maximum may also be explained through a consideration of the time of occurrence of these phases with reference to periastron and apastron. Thus the great amplitude of the minimum of the secondary or rotational curve following periastron may be due to the greater difference in brightness of the brighter and darker areas of the star after its relatively rapid motion in this section of the orbit; and the smaller amplitude at maximum of the rotational curve following apastron passage may be due to the smaller difference between the brighter and darker areas of the star after its slower motion through this section of the orbit.

But the assumed rotational curve in this instance is of peculiar interest because its form may be considered to point to an unsymmetrical brightening of the rotating star. As Loud has pointed out, if the resisting medium diminish the period of revolution sufficiently, the period of rotation may very slightly exceed that of revolution and the point of maximum brightness near the advancing front may move slowly around the star's equator, leaving a trail of diminishing brightness. Then, as the star rotates, bringing into view first the region of greatest brightness and, in their turn, those of declining brightness, there ensues the rapid rise and slow decline of apparent total light characteristic of Cepheid stars. At the same time, a rotational curve somewhat similar in form (and possibly also in amplitude) to that shown here would result; and the effect upon the *observed* velocity curve would be evident in a strong depression in the descending branch, tending to increase the eccentricity, in general, and tending to throw the apparent periastron point into the first and second quadrants. The orbital curve of W. Sagittarii, adopting a secondary of this type, tends toward a circular form.

Under this hypothesis, it seems not impossible that the orbits of the Cepheid stars, studied with the spectrograph, may be considered to be more nearly circular. Further, on this hypothesis, the proportion of light and velocity curves with recognizable irregularities might be such as actually found. And in some cases, as possibly in ζ Geminorum, a close synchronism of rotation and orbital motion may accompany roughly symmetrical (though perhaps irregular) brightening, leading to nearly symmetrical (though perhaps irregular) light and velocity curves. No other hypothesis so far proposed seems to account for so many Cepheid characteristics as that of Loud. But for a typical case with ω in the neighborhood of seventy degrees, if this type of secondary be assumed as due to rotation, the additional assumption, that the brighter area of the star is directed roughly toward the center of the nearly circular orbit, would seem to be suggested.

Up to this point, in considering the systems of ζ Geminorum and W Sagittarii, it has been assumed that the angular rates of rotation and orbital revolution are closely similar and that the direction of each is the same. As to the close identity of the direction of orbital motion and rotation there seems little room for question though the axis of rotation may not be accurately perpendicular to the orbital plane. Further, in case of circular orbital motion there seems to be justification for the assumption, frequently made, that orbital and rotational periods are equal. However, in the consideration of close binary systems of high orbital eccentricity, if this identity be adopted, the resulting librations become so great that serious question arises as to the ad visability of the assumption. If we consider the average Cepheid variable of Table III, we find the eccentricity to be about 0.29. In such a system, if the identity of the orbital and rotation periods be assumed, the excess of the orbital revolution over the angular motion of rotation during periastron passage from latus rectum to latus rectum again is 65°—more than one-third of the change in true anomaly. During the corresponding apastron passage, the extent of this libration is nearly the same; but, as the writer has pointed out, the tidal force varies in the ratio of one to eight between the apastron and periastron points, and the tidal forces are far more effective in the neighborhood of periastron. Thus the question arises: In the case of close binary systems of high eccentricity, will the greater tidal action in the section of the orbit near periastron induce, as the result of tidal friction, an angular velocity of rotation which will follow closely the angular velocity in this part of the orbit?

In a system with an orbital eccentricity of 0.35, if the period of rotation be one-half the orbital period, the same area of each star will be presented to the companion throughout an arc of 73° at periastron with a libration not exceeding 2½°, and throughout an arc of 120° with a libration of 20°. Under the assumption of identical orbital and rotational periods the corresponding librations would be 34° and 41° of stellar longitude. Under these circumstances is it possible that a period of rotation of one-half the orbital period will best satisfy the conditions in the system? Possibly the answer to these highly interesting questions will sometime be found through the study of Cepheid variables.

If the half-period rotation is to account for the irregularities in the velocity curve of such a star as W Sagittarii it seems necessary to assume that there is between two hemispheres of the rotating star a difference of effective brightness semi-permanent in character and not immediately dependent on the action of a resisting medium at any instant if such be assumed. That such a semi-permanent effect may be present in these Cepheid stars seems not unreasonable in view of the relatively higher orbital velocities near periastron and in view of the presentation in orbits of certain eccentricities, of the same face of the star very closely in the direction of orbital motion during ninety degrees of anomalistic motion near periastron. Possibly then the relative brightness differences of the preceding and following faces of the star, set up during motion about periastron, remains a semipermanent feature of the star's surface. If this effect were present, a secondary velocity curve due to a half-period rotation might manifest itself—greatly modified perhaps by more rapid surface changes immediately attending orbital motion. Possibly the components in the velocity curve due to the rapid changes of surface brightness combined with rotation would follow a sine curve closely with a period identical with that of orbital revolution and might not be detected even if relatively great. But the effect of a half-period rotation combined with a considerable permanent difference of relative brightness between two hemispheres might be readily observed.

Already the velocity curve of W Sagittarii has been studied by the writer on the assumption that the period of the secondary curve is half the orbital period. The elements derived are reproduced in Table VIII. The corresponding curve has been published in No. 62 of the *Lick Observatory Bulletins* and in the *Astrophysical Journal*, Volume 20, p. 149. The secondary curve seems to follow a sine curve closely, and the eccentricity of the corresponding orbit of the system is such that the assumed period of rotation seems not unreasonable.

TABLE VIII.—ELEMENTS OF W SAGITTARII.

	PRINCIPAL CURVE	SECONDARY CURVE
P	7.595 days	3.8
ω	70.0 degrees	———
e	0.320	0.0
T	6.20 days	
A	+21.6 km.	+4.2 km.
B	—17.4 km.	—5.5 km.
V_0	—28.6 km.	

The position of the secondary curve considered in connection with the rotation theory advanced above indicates that the brighter face of the star is most nearly directed to the earth at maximum light. Immediately thereafter, as the rotation turns the brighter face away, a secondary light minimum has been observed, according to Pickering. This is followed by a secondary maximum, 3.8 days after the principal maximum, at which phase a cross point of the velocity curves occurs and the more permanently brighter area of the rotating star is again presented to the observer according to the rotation theory. Near principal light minimum the brighter area is again turned away from the observer at the fourth cross point of the secondary curve. Thus some relation between the light curve and the above interpretation of the velocity curve is indicated. The double amplitude of the secondary light oscillation is about 0.24 magnitudes and that of the principal light variation, 0.6 magnitudes.

The velocity curve of ζ Geminorum has also been studied on the assumption that the rotation period is half the orbital period and that a permanent difference of brightness exists between two opposite hemispheres of the principal star. The resulting elements are given in Table IX. In this case the form of the secondary curve is irregular. Also the same face of the visible star is presented to the observer at maximum light and at minimum light on the rotation theory. There seems little to recommend these curves as representing real conditions in this system.

TABLE IX.—ELEMENTS OF ζ GEMINORUM.

	PRINCIPAL CURVE	SECONDARY CURVE
P	10.154 days	5.08 days
ω	58.9 degrees	———
e	0.18	———
T	1.10 days	———
Max. Vel.	+21.5 km.	+4.5 ± km.
Min. Vel.	— 5.5 km.	—4.5 ± km.
V_0	+ 6.8 km.	———

If the rotation theory here outlined be assumed, the more probable additional assumption seems to be that the orbital and rotational periods of ζ Geminorum are closely identical. But on this assumption, there are certain discrepancies to be explained and the resulting secondary oscillation curve differs from a sine curve by quantities about as great as the semi-amplitude of Campbell's third-period secondary. Whereas a rotational effect is probably present, it is not definitely indicated so far as these investigations go. In the case of W Sagittarii there is evidence of a connection of rotational effects with the irregularities observed both in the light and velocity curves.

SUMMARY.

1. Studies of the distribution by periods of the stars of Luizet's list of Cepheid variables indicates that these stars may be divided tentatively into two classes: one with a preference for periods of four to eight days, but possibly including variables with periods up to 100 days or more; the other with periods less than two days.

2. Studies of the relation between average magnitude range and period indicate that these two quantities are connected by a complex relation undoubtedly involving many factors. A well determined curve connecting these two elements is shown in Plate XVIII.

3. On the basis of Ludendorff's equation between velocity and magnitude range in Cepheid variables, a relation between the light period and the average velocity range ought to follow in

accordance with the curve of Plate XVIII. The reality of such a relation is questioned. The relation, $P = 2000/K^2$, is tentatively proposed.

4. Some indication is found of an increase, with increasing systemic velocity, in the observed discrepancy between the times of occurrence of light maxima and velocity minima in Cepheid systems. This relation is possibly in harmony with the assumption of a resisting medium in the system.

5. In accordance with the known light and velocity relations in Cepheid systems, it should be expected, as the known results show, that a preference for the first two quadrants should be exhibited in the values of the angular distance of periastron from the node.

6. On some grounds it seems probable that the surface area, surface luminosity and axial rotation of some Cepheid variables is such that rotational effects in their velocity curves are to be expected. If the superposed curve due to rotation is of small amplitude or differs little from a sine curve of period equal to the orbital period, its presence may not be detected though the elements of the system as derived from the velocity curve will be more or less affected. If the secondary is irregular or different in period from the primary, its presence will be more clearly revealed. If the orbital and secondary periods are alike, the form of these curves will in general be indeterminable. But, keeping the simplest requirements of the rotational effect in mind, principal curves may be selected and the resulting secondary oscillation may be examined.

Preliminary studies of the velocity curve of ζ Geminorum indicate that, while velocity displacements of considerable magnitude may be caused by rotation in this star, no simple application of a rotation theory has accounted definitely for the irregularities observed. The irregularities in the velocity curve of W Sagittarii are perhaps more in harmony with the application of a rotation theory in connection with a theory of unsymmetrical brightening, or in connection with the assumption that the rotation period is one-half the orbital period if such be possible.

CONCLUSION.

It will be noted that appeal has been frequently made in this discussion to the theory that a resisting medium is present in any Cepheid system, which enhances the relative brightness of that side of the visible component which faces the direction of orbital motion. This theory accounts for a number of established facts in connection with these systems.

It is especially interesting to consider the effects that the presence of such a medium might have upon the orbital elements of such a system. If of sufficient density, it is quite possible that its action would reverse, under some circumstances, or balance, under others, the tendency toward a lengthening of the period of revolution resulting from tidal friction and would thus maintain or produce an exceptionally small value of the orbital period in these systems even though they be relatively old. In this way the occurrence of solar type binaries of relatively short period, which is characteristic of many Cepheid variables may be accounted for. On the other hand the well known perturbation in the eccentricity due to the action of a resisting medium on a body moving in an eccentric orbit, might be expected to have tended toward smaller values of the eccentricities in these systems. That the eccentricities so far *observed* in Cepheid systems average large may indicate that the conditions (e. g., tidal friction) favorable to increasing eccentricity, which have operated in the average binary system old enough to have assumed the solar type spectrum, may also have predominated here in their influence upon departure from orbital circularity.

At the same time, it seems quite possible that the *true* orbital curves of the Cepheid stars are, as a rule, nearly circular. The eccentricity as well as the irregularities of the *observed* velocity curves may be due to the superposition of unsymmetrical rotational displacements, explicable on the basis of some theory similar to that of Professor F. H. Loud, discussed briefly above.

August 1, 1913.

STUDIES OF THE SPECTRA OF DELTA AND EPSILON ORIONIS

By RALPH H. CURTISS

The recent discovery by Stebbins of light variations due to eclipses in the system of δ Orionis has made desirable a reinvestigation of the orbital elements of this star in order that recently observed velocities may supplement the light measures in the determination of the constants of this system. In addition, spectroscopic studies of this star are of especial value in themselves at this time because of the fact that this is one of a very few short period binaries of which reliable elements are determinable, dating back eleven years, making possible the accumulation of some evidence with reference to the variability of the orbits of close systems. Also in connection with this star, further studies of the sharp apparently fixed K line of Calcium, discovered by Hartmann, are desirable, as well as an inspection of the visual region of the spectrum.

The spectroscopic study of ϵ Orionis was undertaken at this time chiefly in order to throw light upon the question of the availability of this star as a reliable comparison source, in which capacity it had been used by Stebbins in all his observations of δ Orionis. In this connection it is important to know the period and extent of the velocity variations. Considerable interest also attaches to the study of the velocities obtained from the H and K lines in the spectrum of this object, and to the inspection of the visual region of this spectrum.

These considerations have led to the inclusion of these two stars in our rather limited observing list of miscellaneous objects apart from our regular programs of spectroscopic work.

δ ORIONIS.

The Total Light.

The visual magnitude of δ Orionis ($\alpha = 5^h\ 27^m$, $\delta = -0^\circ\ 22'$), as given in the Revised Harvard Photometry, is 2.48; and in view of the character of the spectrum the photographic magnitude may be taken as 0.3 of a magnitude brighter. A variation of the visual brightness of this star (between the magnitude limits, 2.2 and 2.7, according to Schönfeld) was thought by J. Herschel to have been detected by him, but subsequent observations by various observers have led to contradictory results. Auwers considered that he had established in 1854, and followed until 1858, a regular variation of the light with a period of 16.08 days, a quantity nearly equal to three times the orbital period. Later observers, including Chandler and Sawyer, failed to confirm Auwers' results and attributed the variations observed by him to difficulties due to the low altitude of this star. δ Orionis is not included in recent catalogs of variable stars.

Professor J. Stebbins detected and studied eclipse variations, with double minima, in the light of δ Orionis and announced his results before the Astronomical and Astrophysical Society of America in 1911. The photometric observations and light curve, which he has kindly furnished me, indicate that the magnitude range of the light variation as measured with the selenium cell is 0.10 magn., that the phases of the light minima synchronize closely with those of orbital conjunction, and that the light variation is probably continuous like that of a β Lyrae variable. A striking but by no means unprecedented feature of this light curve is found in a pronounced asymmetry of the depressions at the minima. It was this feature which led more particularly to the spectral studies at the Detroit Observatory, which are described in this paper.

THE SPECTRUM.

In the Harvard Annals the spectrum of δ Orionis as well as that of ϵ Orionis is assigned to Class B of which the latter star is chosen as a typical object. Much detail with reference to the measurable lines in these spectra will be found in Table I, the first two columns of which contain the wave-lengths determined by Hartmann for δ Orionis as well as the lines used by him in velocity determinations. The next four

columns contain the wave-lengths, relative intensities, number of measures and probable errors of the lines in the same star as studied by the writer; columns 7 to 10, similar data by the writer for ϵ Orionis; and the last two columns of the table, the wave-lengths adopted by the writer in this paper together with partial identification and assignment of authority.

Comparing columns 1 and 5 it is evident that the character of the spectra measured by Hartmann and the writer was essentially the same and that there had been no important changes in the photographic spectrum in eleven years. Differences in opinion as to the availability of a few difficult lines for velocity work are accountable on the basis of instrumental differences and very slight differences of judgment. If there has been any real change in this spectrum since the epoch of Hartmann's spectrograms it may be found in λ 4481 of magnesium which Hartmann employed in his velocity determinations and which the writer found to be an extremely difficult line and one not available for velocity work.

A comparison of columns 3 and 4 with columns 7 and 8 of Table I brings out interesting differences between the lines of the spectrum of δ Orionis and those of the typical Class B spectrum of ϵ Orionis. The presence of a greater number of measurable lines in column 7 is due partly to the superior definition of all lines in the spectrum of ϵ Orionis but also to real differences of intensity between lines found in this star and their counterparts in δ Orionis. Consulting the intensities, in columns 4 and 8, which are the means of the estimates made at each measurement of each line, it will be seen that there is a striking resemblance between the absolute intensities in these two stars of the lines of helium and the Huggins series of hydrogen, while the two representatives of the Pickering series and Fowler's principal series line at λ 4686 are certainly stronger in δ Orionis. Of the three strong lines near Hδ, λ 4089 is of equal intensity in both spectra while the other two are considerably stronger in ϵ Orionis. Metallic lines, such as λ 4481 of magnesium, λ 4553, λ 4568 and λ 4575 of silicon, are decidedly stronger and better defined in ϵ Orionis. Apparently, according to present ideas, the spectrum of δ Orionis corresponds to an earlier stage of evolution than that of ϵ Orionis.

The wave-lengths in this table with their probable errors require very little discussion at this time. It is expected that they will be of value in connection with studies of variation of wave-length in stellar spectra from type to type. Possibly the most interesting difference between the adopted wave-length and that found from the measures is met with in the case of Hδ. The adopted value, λ 4101.92, was derived from measures of spectra of stars somewhat more advanced in type than is δ Orionis. In the spectra of these stars a measurable nucleus is often found in the Hδ line, a feature not found in this line in δ Orionis. In ϵ Orionis, where this line is much sharper than in δ, the wave-length of Hδ conforms more closely to the value for stars of later type.

The exceedingly diffuse appearance of the absorption lines in δ Orionis has been commented on by Hartmann. He says, "On account of the slight intensity of the lines, all defects of the film are very disturbing and, in consequence of the irregular distribution of the silver grains, the lines often appear crooked and unsymmetrical, sometimes indeed double. I have convinced myself by a special investigation that the indications of duplicity and unsymmetrical broadening cannot be caused by lines belonging to a second component of the stellar system; but I do not hold it to be impossible that the form of the lines is subject to small real changes, perhaps in consequence of violent motions in the gaseous envelope of this star."

TABLE I. WAVE-LENGTHS OF LINES IN THE SPECTRA OF δ AND ε ORIONIS.

δ Orionis						ε Orionis					
Hartmann		Curtiss				Curtiss					
Wave-lgth.	No. Meas.	Wave-length	Int.	No. Meas.	P. E.	Wave-length	Int.	No. Meas.	P. E.	Adopted Wave-length	Authority and Identification
(1) Å	(2)	(3) Å	(4)	(5)	(6) Å	(7) Å	(8)	(9)	(10) Å	(11) Å	(12)
Assumed	..	....	....	..	.....	3889.13	22.–	3	±0.077	....	Hζ.
3933.68	7	....	3.0	43	.....	....	4.0	27	.....	3933.825	K. Rowland.
....	..	....	....	..	.....	3964.70	4.2	7	0.044	....	Helium.
....	..	....	2.6	21	.....	....	3.5	12	.....	3968.625	H. Rowland.
Assumed	..	3970.30	17.2	21	±0.037	3970.22	16.1	14	0.029	3970.18	Hε. Rowland.
....	..	....	....	..	.....	4009.50	3.7	6	0.025	4009.42	Runge and Paschen.
Assumed	..	4026.33	17.8	66	0.015	4026.34	13.7	30	0.012	4026.37	Runge and Paschen.
4069.49	3	....	....	..	.....	....	....	..	.....	....	....
....	..	....	....	..	.....	4076.02	4.3	12	0.034	....	Oxygen.
Assumed	..	4089.19	15.4	41	0.032	4089.08	14.5	30	0.011	4089.00	Si. Lunt.
4097.49	5	....	....	..	.....	4097.56	6.8	22	0.028	4097.47	N or Si.
Assumed	..	4102.11	25.9	68	0.018	4102.01	25.5	22	0.018	4101.92	See text. Hδ.
4116.28	11	4116.31	8.4	47	0.019	4116.31	11.0	30	0.009	4116.30	Lunt and Hartmann.
....	..	4121.01	5.1	8	0.095	4120.88	5.2	10	0.048	4121.02	Runge and Paschen.
4143.94	2	4144.07	5.8	6	0.042	4143.87	5.8	21	0.021	4143.92	Runge and Paschen.
4200.42	2	4200.17	4.8	5	0.058	4200.28	3.4	4	0.084	....	Hδ'.
....	..	....	....	..	.....	4253.81	3.1	14	0.050	....	Sulphur
....	..	....	....	..	.....	4267.42	3.5	4	0.093	4267.15	C. Eder and Valenta.
....	..	....	....	..	.....	4317.27	2.6	5	0.11	....	Oxygen.
....	..	....	....	..	.....	4319.76	2.5	6	0.091	....	Oxygen.
Assumed	..	4340.56	16.8	72	0.012	4340.65	18.9	31	0.020	4340.63	Hγ. Rowland.
....	..	....	....	..	.....	4345.78	2.–	3	0.18	....	Oxygen.
....	..	....	....	..	.....	4349.85	3.5	11	0.071	....	Oxygen.
Assumed	..	4388.06	7.0	51	0.028	4388.04	6.7	29	0.023	4388.10	Runge and Paschen.
Assumed	..	4471.61	11.8	72	0.015	4471.68	10.7	31	0.013	4471.68	Runge and Paschen.
Assumed	..	....	....	..	.....	4481.38	2.3	6	0.052	4481.40	Mg. Frost.
4541.78	2	4541.72	5.3	14	0.040	4542.02	3.2	6	0.090	....	Hγ'.
....	..	....	....	..	.....	4552.76	5.2	25	0.025	4552.76	Si. Albrecht.
....	..	....	....	..	.....	4567.94	3.8	21	0.038	4567.97	Si. Albrecht.
....	..	....	....	..	.....	4574.74	2.6	7	0.036	4574.92	Si. Albrecht.
....	..	....	....	..	.....	4638.48	2.2	6	0.15	....	Blend.
....	..	....	....	..	.....	4641.87	6.8	12	0.11	....	Oxygen.
....	..	4647.90	7.0	11	0.12	4647.74	9.9	19	0.042	....	First Component.
4649.68	16	4649.56	26.1	61	0.038	4649.42	28.3	30	0.015	....	Blend.
....	..	4650.93	9.2	11	0.10	4650.63	12.1	19	0.040	....	Second Component.
....	..	....	....	..	.....	4661.72	2.8	5	0.15	....	Oxygen.
4686.20	10	4686.14	7.4	41	0.041	4686.01	4.6	10	0.075	4686.00	Hydrogen.
....	..	4713.36	7.0	31	0.039	4713.32	6.8	26	0.031	4713.31	Runge and Paschen.
Assumed	..	4861.50	16.2	46	0.024	4861.51	13.9	26	0.046	4861.53	Hβ. Rowland.
Assumed	..	4922.10	7.7	7	±0.097	4922.10	8.7	15	±0.048	4922.10	Runge and Paschen.

NOTE.—The probable errors in columns 6 and 10 of Table I are based on the agreement of the wave-lengths deduced from the several plates. These probable errors do not include the systematic uncertainties (of the order of one or two hundredths of an Angstrom) affecting the determination of wave-lengths by the corrected Hartmann interpolation curve.

In view of presence of effects in the light curve due the light of the "companion" of δ Orionis, it would seem that Hartmann's statement with reference to the absence of effects due to lines of the second component might well be reconsidered. Accordingly, during my own measures, I have watched carefully for the lines of this second component, but with uncertain success. At phases near velocity minimum I have measured on four of my plates close lines of intensity "3" on the edge of longer wave-length of some of the stronger lines in seven cases, giving a mean value of + 70 km. Whereas it is possible that these satellites belong to the first component, velocities consistent with the other lines are obtained by considering that they do not. If these satellites are due to a second component, this would indicate that the mass of this body is about 1.8 that of the primary and we would expect to find similar lines in a position corresponding to a negative displacement of about 40 km., at the phase of the velocity maximum of the primary; and at this phase there are five or six lines on four or five plates which might be ascribed to this second component. But obviously the evidence here is very weak. If the lines of the second component are strong enough to be seen it is possible that they are always hopelessly blended with the lines of the principal star. It is possible that some of the "structure" observed in the lines of δ Orionis is attributable to the lines of the second component as well as to the causes suggested by Hartmann; and also the possibility remains that anomalous dispersion plays a part here as suggested by Julius.

The structure of the lines in δ Orionis' spectrum presents an interesting but difficult problem. In the case of λ 4089 the variations of the line are so complex that I have not used it in velocity determination, though in ε Orionis the same line yields satisfactory results. On all the lines, my studies, like those of Hartmann, have brought out little evidence of relation between phase and structure change of lines.

One peculiarity, frequently observed in the lines of this spectrum, is an asymmetry due to greater diffuseness of one edge. It will be remembered that Schlesinger found that these shadings in the lines of the spectrum of λ Tauri were always toward the normal position of these lines. For three of the lines (Hγ, λ 4471 and Hβ) in the spectrum of δ Orionis, the writer finds 100 cases of symmetry, 26 cases with shadings toward the normal positions of the lines and 14 cases with shading away from it. Close absorption was observed more frequently on the side toward the normal position of the line, than on the far side, but this effect in δ Orionis is not pronounced.

On three spectrograms of the visual region of the spectrum of δ Orionis the writer has measured the better lines for approximate wave-length determination and has estimated the intensities of these lines on the scale used in Table I. The results compared with those for ε Orionis are given in Table II. In the case of the identified lines the wave-lengths in this table were assumed. The relative weakness of Hβ′ in ε Orionis was not unexpected but that of Hα had not been anticipated. Possibly the emission seen clearly at the edges of the Hγ and Hβ lines has increased in this region at the expense of the enclosed absorption. In view of the faintness of K in δ Orionis, the absence of measurable impressions of the D lines of sodium is not unexpected.

TABLE II. WAVE-LENGTHS IN THE VISUAL REGION.

δ Orionis λ	δ Orionis int.	ε Orionis λ	ε Orionis int.	Identification
4862	16	4862	14	Hβ. Hydrogen.
5016	5	5016	8	Helium.
5414	8			Hβ′. Hydrogen.
5448	6			
		5653	5	
5876	12	5876	12	D3. Helium.
		5890	3	D2. Sodium.
		5896	3	D1. Sodium.
6086	7			
6275	15	6275	10	
6280	7			
6328	6			
6563	10	6563	6	Hα. Hydrogen.

FORMER RADIAL VELOCITIES.

The earliest known velocities of δ Orionis were determined by Vogel and Scheiner from four plates made in the years 1888 to 1891. Because of the historic value of these observations they are given in the accompanying table. The

first measures show no evidence of variation, but the revised measures, made by Vogel ten years later with a knowledge of the established variation, are not inconsistent with later results. These early velocities were determined entirely from the Hγ line, across which fell the artificial line of the same element, making accurate measures exceedingly difficult.

TABLE III. EARLY POTSDAM OBSERVATIONS.

DATE	GR. M. T.	FIRST VEL.	REVISED VEL.	RESIDUAL
1888	Dec. 10.37	−3 km.	−9 km.	+10 km.
1889	Jan. 5.34	±0	+4	−24
1891	Feb. 26.26	+2	−55	−6
	27.26	+4	+13	−35

The velocity variation of δ Orionis was discovered by M. Deslandres from eleven spectrograms made in December, 1899, and the following month, with a new spectrograph attached to the 62 cm. refractor of the observatory at Meudon. From these eleven observations, Deslandres derived a period of 1.92 days and concluded that the orbit was highly eccentric.

After the publication of Deslandres' discovery, which was communicated to the Paris Academy on February 12, 1900, confirmatory observations were made at once at Potsdam and, in the following season, by Wright at the Lick Observatory. But the velocity variation observed at Potsdam did not conform to Deslandres' period and since a fuller investigation seemed desirable, partly perhaps because of the lack of variation in the early Potsdam velocities, a set of thirty-seven one-prism spectrograms was made by Hartmann with the Potsdam 80 cm. refractor in the winter months of 1901-2 and 1902-3. The dates of these observations and the corresponding velocities will be found in Table IV of this paper.

TABLE IV. HARTMANN'S POTSDAM OBSERVATIONS. (Spectrograph I.)

DATE	GR. M. T.	PHASE DAYS	VELOCITY KM.	RESIDUAL KM.	WT.
1901	Nov. 23.421	0.836	+ 63.5	+ 4.0	1.0
1902	Jan. 13.305	0.128	− 3.3	+12.8	0.7
	.399	0.222	+ 6.1	+13.0	0.5
	14.356	1.178	+ 92.2	− 6.0	0.4
	.441	1.263	+110.5	+ 5.0	0.7
	16.357	3.179	+ 27.0	+ 4.4	1.0
	Feb. 4.424	5.049	− 65.0	− 1.2	1.0
	10.368	5.260	− 45.1	+11.8	1.0
	11.256	0.416	+ 17.8	+ 4.8	1.0
	12.240	1.400	+124.9	+ 8.7	0.4
	13.224	2.384	+107.1	+ 1.8	1.0
	14.226	3.386	+ 3.9	+ 2.0	1.0
	15.196	4.356	− 63.0	− 1.8	1.0
	16.209	5.369	− 52.3	− 0.8	1.0
	Mar. 5.264	5.227	− 59.6	− 1.6	0.7
	6.226	0.457	+ 27.3	+ 8.7	1.0
	11.305	5.535	− 43.5	− 2.5	1.0
	12.235	0.733	+ 45.4	− 4.5	1.0
	13.232	1.730	+128.4	− 2.0	1.0
	14.238	2.736	+ 68.7	− 3.0	0.7
	Apr. 2.259	4.559	− 79.5	−13.0	1.0
	2.307	4.607	− 60.0	+ 7.3	1.0
	9.295	0.131	− 30.0	−14.5	0.7
	10.282	1.117	+ 81.2	− 9.6	1.0
	Dec. 11.385	5.456	− 49.3	− 3.0	1.0
	12.370	0.709	+ 47.2	+ 0.3	1.0
	13.367	1.706	+128.7	− 1.2	1.0
	14.459	2.798	+ 56.1	− 8.6	1.0
1903	Jan. 9.339	0.016	− 32.7	− 8.0	0.7
	12.391	3.067	+ 38.2	+ 2.9	0.7
	13.342	4.018	− 46.4	− 1.4	1.0
	14.320	4.996	− 69.3	− 4.1	1.0
	17.355	2.299	+127.1	+14.3	0.5
	Feb. 7.369	0.383	0.0	−10.0	1.0
	Mar. 7.228	5.312	− 54.9	− 1.0	0.5
	12.244	4.595	− 61.2	+ 6.2	0.5
	15.256	1.875	+135.4	+ 5.0	1.0

Hartmann's memorable discussion of these observations is found in the *Astrophysical Journal*, Volume 19, pp. 268 to 285. On the basis of his own and the early revised Potsdam measures he deduces an apparent period of 5.7325 ± 0.0002 days for the velocity oscillation and through a preliminary reduction derives the remaining orbital elements:

$$
\begin{aligned}
e &= 0.10334, \\
\omega &= 339^\circ\ 18'.9, \\
T &= 1902,\ \text{Feb. } 12.35, \\
K &= 100.8\ \text{km.}, \\
a \sin i &= 7{,}906{,}600\ \text{k.m.}, \\
m_1^3 \sin^3 i/(m_1 + m)^2 &= 0.601\odot.
\end{aligned}
$$

On the basis of the latter quantity he considers that the total mass of the system is certainly greater than the solar mass, and probably of the order of from five to ten times the solar mass.

Possibly the most interesting result in his

paper is found in the statement, ". . . the calcium line at λ 3934 does not share in the periodic displacements of the lines, caused by the orbital motion of the star." This discovery has raised a problem which, notwithstanding much well directed research, does not appear to be fully solved. Hartmann's ingenious explanation for this remarkable observation is found in ". . . the assumption that, at some point in space in the line of sight between the sun and δ Orionis, there is a cloud which produces this (K) absorption."

The importance of Hartmann's observations of δ Orionis, especially in connection with the Ann Arbor velocities, is such that a least square solution has been made in connection with the reductions of the present paper; and as a preliminary step normal places have been formed in Table V. It is not stated whether the times of observation have been reduced to the sun but the correction involved may be omitted here. The phases have been computed on the basis of a preliminary period, P = 5.73248 ± 0.000,022 days, determined by a combination of Potsdam and Ann Arbor observations. The epoch adopted is 1900, Feb. 24. 2800, G. M. T. The hundredth of a kilometer occurring in this table is, of course, of little significance except as a check upon the computations. In forming the normal places, it was necessary to adopt a system of weighting for the individual plates. This raised some interesting questions which may now be discussed.

TABLE V. NORMAL PLACES (HARTMANN'S OBSERVATIONS).

WEIGHTS BASED ON NUMBER OF LINES MEASURED.

NO.	PHASE DAYS	VELOCITY KM.	RESIDUAL KM.	WT.
1	0.132	− 11.4	+2.0	1.000
2	0.421	+ 15.3	+0.6	0.714
3	0.758	+ 54.4	+2.9	0.643
4	1.206	+ 97.1	−1.7	0.964
5	1.770	+131.0	−0.5	0.679
6	2.332	+118.8	+5.9	0.536
7	2.766	+ 63.5	−7.1	0.500
8	3.199	+ 23.6	+2.0	0.714
9	4.177	− 55.2	+1.3	0.464
10	4.588	− 66.2	+1.1	0.821
11	5.022	− 66.5	−3.0	0.393
12	5.266	− 53.8	+0.7	0.821
13	5.453	− 48.4	−3.9	0.750

WEIGHTS BASED ON MEAN ERRORS.

NO.	PHASE DAYS	VELOCITY KM.	RESIDUAL KM.	WT.
1	0.117	− 16.78	−0.19	0.9
2	0.419	+ 14.98	+1.40	1.0
3	0.759	+ 52.06	+0.02	1.0
4	1.215	+ 98.83	−2.10	0.8
5	1.770	+131.28	+0.35	1.0
6	2.355	+114.02	+5.74	0.5
7	2.772	+ 61.29	−6.64	0.6
8	3.227	+ 20.97	+2.38	0.9
9	4.187	− 55.67	−0.30	0.7
10	4.586	− 68.09	−0.68	0.8
11	5.022	− 67.25	−2.36	0.7
12	5.261	− 51.99	+4.73	0.7
13	5.453	− 48.55	−1.89	1.0

The weighting of velocities obtained from plates containing stellar spectrum lines relatively few in number and differing widely in quality, is always attended with difficulties. In connection with his own observations of δ Orionis the author has adopted a system, described below, which seems to him satisfactory in determining the probable worth of a plate. But for the reduction of observations published by others the data are usually not available for the use of this system.

Hartmann has published for each velocity of δ Orionis the number of lines measured and the mean error deduced presumably from the internal residuals of the lines on each plate. In general it would seem reasonable to assume that the weight to be assigned the velocity deduced from one plate, of a number of the same star, should increase with the number of lines measured, in which case we should expect the mean error of the velocity derived from a plate to decrease with an increase in the number of lines used—though in no simple relation since in a velocity based on measures of more than the average number of lines available on plates of a given star, more than the usual proportion of poor lines are frequently included. Referring to the observations here considered we find that the mean errors do not stand in the expected relation to the number of lines. The average number of lines measured on each of the plates is almost exactly seven. And the average mean error for the whole set of plates is ± 5.6 km. For the

eleven plates having from eight to ten measurable lines the average mean error is ± 6.5 km.; and for the sixteen plates having from two to six measurable lines the average mean error is ± 5.5 km. Referring also to the residuals for these plates from Hartmann's velocity curve we find that the mean absolute residual for the plates containing more than seven lines is 6.5 km., while that for the plates containing less than seven lines is 3.9 km. It is possible that the lines added in making up the larger total of any plate received too much weight in the mean. It seems probable, however, that certain lines, for which the assumed wave-lengths yielded velocities more discordant than the average, were usually included in the measures of plates having the greater numbers of lines available.

If this be the case it would seem that the measures based on a greater number of lines per plate may be of greater value as yielding absolute velocities under these circumstances, whereas the velocities from plates on which lines equal to or somewhat less than the average in number are measured, possess greater relative accuracy. Accordingly plates of this latter class should receive the greater weight in connection with orbital determination, unless the necessary steps have been taken to reduce all wave-lengths used to a homogeneous system.

Obviously it would be unsafe to make the weight of each plate inversely proportional to the square of its mean error. It has seemed better to divide the plates into groups according to the number of lines measured, to derive the average mean error of each group, to plot these average mean errors with number of lines measured as abscissae, and to take from a smooth curve, drawn through such plotted points, the mean error, corresponding to the number of lines measured on any plate, as the best mean error for that plate. The mean errors and weights thus derived are given in the following table. The curve of mean errors here derived is quite similar to though flatter than the corresponding curve of average residuals based upon Hartmann's orbital elements.

TABLE Va. DERIVATION OF WEIGHTS.

NO. LINES	MEAN ERROR: AVERAGE COMPUTED KM.	MEAN ERROR: FROM CURVE KM.	WEIGHT	NO. PLATES
10	± 8.4	∓ 8	0.4	1
9	6.9	7	0.5	4
8	6.1	6	0.7	6
7	4.5	5	1.0	10
6	5.4	5	1.0	13
5	3.5	5	1.0	1
4	...	6	0.8	0
3	4.7	6	0.7	1
2	9.5	8	0.4	1

A practice solution of the observations of Table IV using weights directly proportional to the numbers of lines was carried out by Messrs. W. C. Rufus and L. M. Coffin at this observatory. Since these elements resulting from this solution are of interest in connection with the quantities deduced with modified weights, the details of the work may be briefly given.

The data of the normal places are given in columns 2 to 5 of Table V. The preliminary elements were computed by the forty-five degree chordal method.

PRELIMINARY ELEMENTS

$P = 5.73248$ days,
$e = 0.096$,
$\omega = 347° \ 41'$.
$T = 1902$, Feb. 12.508,
$K = 100.0$ km.,
$\gamma = +23.22$ km.

The results of the least square solution follow. Though the maximum difference between final velocities computed with elements and from equations was somewhat large (0.46 km.) a second solution would yield unimportant changes. By this solution, the sum of the weighted squares of the residuals for the normal places was reduced from 1165 to 753.

ELEMENTS (WEIGHTS BASED ON NUMBER OF LINES.)

$P = 5.73248 \pm 0.000{,}022$ days (assumed),
$e = 0.095 \pm 0.009$,
$\omega = 3° \ 41' \pm 6°.5$,
$T = 1902$. Feb. 12.742, $\pm$ 0.102 days,
$K = 99.98$ km.,
$\gamma = +22.80$ km.,
$a \sin i = 7{,}847{,}00$ km.,
$m_1^3 \sin^3 i/(m_1 + m)^2 = 0.587 \odot$.

The probable errors of the elements here are derived from the residuals for the normal places. In this case these probable errors would be about fifteen per cent larger if based on the individual plate residuals.

In the second least square solution of Hartmann's observations, which was made by the writer, the plate velocities were weighted as in column 6 of Table IV on the basis of Table Va. The data for the normal places are contained in columns six to nine of Table V. The weights in column nine are directly proportional to the sum of the weights of the plates combined into any normal place. Except for the change of weights, the data are used as in the first solution.

Assuming as preliminary the elements resulting from the first solution, and employing Schlesinger's adaptation of the formulae of Lehmann-Filhes, the normal equations become

$$
\begin{array}{llllll}
+10.60\,\Gamma & & & & & \\
-1.836\,\kappa & -2.498\,\pi & +4.857\,\epsilon & -1.913\,\tau & +8.11 & =0 \\
+5.14 & +0.805 & -0.298 & +0.540 & -2.74 & =0 \\
 & +5.459 & -1.457 & +4.465 & -2.20 & =0 \\
 & & +3.420 & -1.134 & +3.53 & =0 \\
 & & & +3.677 & -1.14 & =0
\end{array}
$$

The values of the unknowns are found to be

$$
\Gamma = -0.563,\ \kappa = -0.241,\ \pi = +19.84,
$$
$$
\epsilon = +0.237,\ \tau = -23.95.
$$

From these the *final elements* resulted:

FINAL ELEMENTS, δ ORIONIS (POTSDAM).

$$
\begin{aligned}
P &= 5.73248 \pm 0.000{,}022 \text{ days (assumed)},\\
e &= 0.0939 \pm 0.0089,\\
\omega &= 352^\circ.3 \pm 6^\circ.9,\\
T &= 1902, \text{ Feb. } 12.562 \pm 0.108 \text{ days},\\
K &= 99.76 \pm 1.06 \text{ km.},\\
\gamma &= +22.14 \text{ km.},\\
a \sin i &= 7{,}829{,}000 \text{ km.},\\
m_1^3 \sin^3 i/(m_1+m)^2 &= 0.583\,\odot.
\end{aligned}
$$

By this solution the sum of the weighted squares of the residuals for the normal places was reduced from 922 to 772. The probable error of a normal place of weight one proves to be ± 2.10 km. and that of the weakest normal place, ± 3.0 km. In view of the magnitude of these quantities, the discrepancies due to the rejection of second order terms in the least square solution, amounting in the maximum to 0.28 km., and averaging 0.12 km., indicates that a repetition of the solution would lead to no important changes.

The curve corresponding to these elements is shown as a full line in the upper figure of Plate XX. Residuals scaled approximately from this curve for the several plates are given in the fourth column of Table IV. On the basis of these residuals the probable error of a plate of weight one is ± 4.5 km., and for a plate of average weight, ± 4.9 km. The value of this latter quantity corresponding to Hartmann's elements was ± 5.1 km.

For comparison with the new value of the velocity of the system, we may quote Hartmann's velocity from the fixed K line of calcium: + 16 ± 1.2 km. Though the wave-length upon which this velocity was based is not given it was presumably very close to the value due to Rowland.

Comparing the two sets of elements based on two systems of weights it will be seen that the differences are not greater than we might expect, in view of the probable errors, from two different sets of observations. It is interesting to note that such differences may arise between the results of two solutions of the same observations each based on a system of weights which any computer might adopt. Apparently the question of weights is one to which the computer should give close attention. In connection with the Ann Arbor observations this point will be further discussed.

THE ANN ARBOR RADIAL VELOCITIES.

The observations of the spectrum of δ Orionis made at the Detroit Observatory include seventy-four measurable spectrograms all of which were made with a single prism spectroscope attached to the 37½″ Reflector. For a detailed description of these instruments the reader is referred to earlier papers in this volume. With a few exceptions the spectrograms were made upon lantern slide plates with average exposures of 8 to 10 minutes. For the study of the K line more especially, the fine grained plates were well nigh indispensable. Four plates were sensitized in the visual region.

The pertinent data in connection with these observations are found in Table VI. The phases, which were first computed with the period,

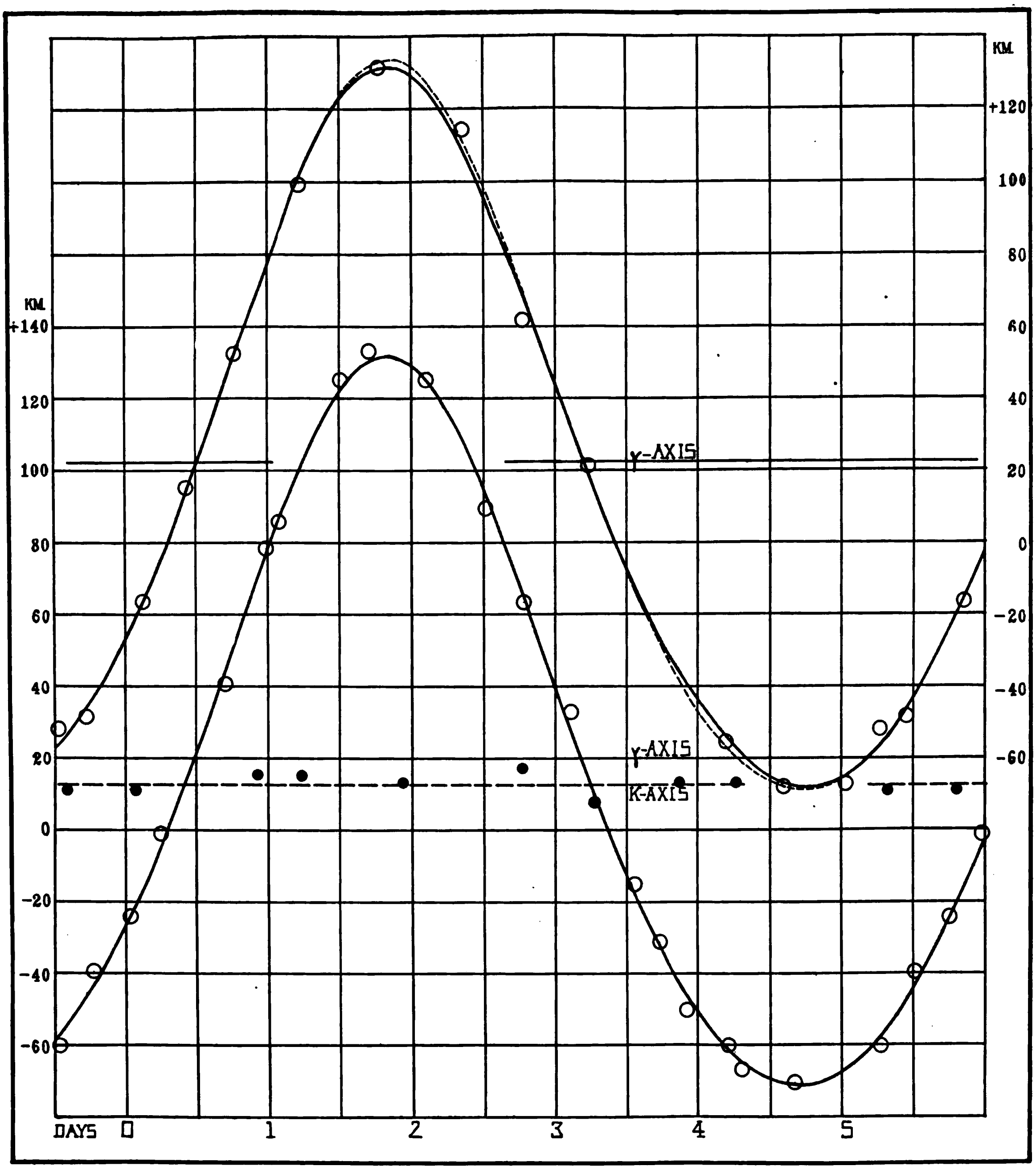

PLATE XX. VELOCITY CURVES OF δ ORIONIS.
OBSERVATIONS OF UPPER CURVE BY HARTMANN. 1901-1903.
LOWER CURVE BY CURTISS. 1912-1914.

5.73248 days, are based on the epoch, 1913, Sept. 11.410. The small corrections necessary to reduce these phases to the sun and to correct for the final period have been applied.

Thirteen lines, indicated in Table I, were used to determine absolute velocities from the plates of δ Orionis and three additional lines, λ's 4200, 4541, and 4650, were used to improve the relative values of the velocities. In determining the velocities of column seven of Table VI, the wave-

TABLE VI. THE ANN ARBOR OBSERVATIONS.

NO. OF PLATE	OBSERVER	DATE, G. M. T.		PHASE	OSCILLATING LINES NO.	WT.	VEL.	RESID.	K LINE VEL.	WT.	H LINE VEL.	WT.
(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		1912	d	d			km.	km.	km.		km.	
323	Curtiss	Mar.	12.602	2.507	9	12	+ 87.0	− 6.5	..	...	..	...
324	Curtiss		12.608	2.513	8	12	+ 86.2	− 5.6	..	...	..	...
1524	Mellor	Nov.	29.878	1.096	9	10	+ 88.8	+ 0.1	+12	2	..	...
1525	Mellor		29.884	1.102	8	11	+ 90.7	+ 1.2	+14	2	+16	1
1535	Curtiss		30.735	1.953	7	6	+129.9	+ 0.0	+18	1	..	...
1559	Curtiss	Dec.	14.777	4.530	4	3	− 74.6	− 4.8	..	...	..	...
		1913										
1578	Curtiss	Jan.	12.763	4.852	5	8	− 67.7	+ 2.5	+23	1	..	...
1583	Mellor		24.672	5.296	8	10	− 67.5	−11.3	+ 7	2	+23	1
1584	Mellor		24.696	5.320	7	9	− 62.8	− 7.5	..	...	..	...
1596	Mellor		28.687	3.578	5	7	− 20.6	− 0.1	..	...	..	...
1597	Mellor		28.699	3.590	7	6	− 15.5	+ 7.0	..	...	..	...
1604	Curtiss	Feb.	8.667	3.095	7	9	+ 33.0	+ 5.6	± 0	½	..	...
1605	Curtiss		8.687	3.114	7	8	+ 31.9	+ 6.0	± 0	2	+ 2	1
1618	Mellor		17.678	0.638	7	7	+ 30.3	− 8.0	..	...	..	...
1619	Mellor		17.689	0.649	5	6	+ 44.0	+ 4.5	..	...	+16	1
1654	Curtiss	Apr.	6.610	2.706	4	4	+ 60.0	−10.2	..	...	..	...
2325	Mellor	Sept.	22.887	0.013	9	7	− 28.0	− 3.3	+11	1	..	...
2349	Mellor	Oct.	3.889	5.283	10	12	− 64.7	− 7.9	+ 7	1½	..	...
2350	Mellor		3.895	5.289	7	9	− 51.2	+ 5.3	+ 5	1	..	...
2370	Curtiss		9.815	5.477	6	8	− 36.8	+ 9.0	+ 6	1	+18	½
2371	Curtiss		9.835	5.497	6	10	− 37.0	+ 7.6	+19	1	..	...
2407	Curtiss		25.800	4.265	7	6	− 60.1	+ 3.4	+15	1	+15	1½
2408	Curtiss		25.818	4.283	9	9	− 67.2	− 3.0	+19	1	..	...
2420	Curtiss	Nov.	1.776	5.510	7	8	− 52.8	− 8.7	+12	2	+ 5	1
2421	Curtiss		1.805	5.539	9	8	− 42.4	− 0.2	+12	1	+16	2
2462	Mellor	Dec.	3.794	3.133	11	10	+ 30.1	+ 6.2	..	...	..	...
2463	Mellor		3.815	3.154	9	7	+ 25.9	+ 4.4	..	...	..	...
2466	Curtiss		4.818	4.158	8	8	− 50.4	+ 8.3	+ 8	2	+24	1½
2467	Curtiss		4.844	4.184	8	6	− 65.3	− 5.2	+13	2	..	...
2478	Mellor		8.819	2.427	7	6	+102.9	+ 0.4	..	...	+29	½
2479	Mellor		10.715	4.323	6	6	− 70.1	− 5.0	+17	2	..	...
2480	Mellor		10.729	4.337	10	8	− 69.5	− 4.0	+10	2	..	...
2491	Curtiss		13.792	1.668	9	9	+132.5	+ 3.4	+ 7	2	..	...
2492	Curtiss		13.837	1.713	9	9	+136.3	+ 6.3	..	...	..	...
2493	Curtiss		13.859	1.735	6	5	+127.6	− 1.8	..	...	..	...
2494	Curtiss		13.892	1.767	2	2	+131.7	+ 0.8	..	...	..	...
2498	Merrill		14.680	2.555	8	9	+ 86.6	− 2.4	+ 6	1	+19	½
2512	Curtiss		18.774	0.918	7	7	+ 73.1	+ 4.0	..	...	..	...
2513	Curtiss		18.833	0.977	9	6	+ 87.3	+ 1.6	..	...	..	...
2538	Mellor	Jan.	13.694	3.907	9	8	− 50.6	− 4.8	+12	1	..	...
2539	Mellor		13.714	3.927	9	8	− 57.3	−10.3	..	...	..	...
2546	Mellor		17.708	2.188	7	8	+125.1	+ 6.2	+21	1	+39	1
2547	Mellor		17.728	2.208	8	7	+122.6	+ 4.8	+12	1	..	...
2560	Mellor	Feb.	4.731	3.013	6	5	+ 46.5	+ 9.0	..	...	..	...
2565	Curtiss		5.630	3.912	7	8	− 44.7	+ 1.8	− 2	1	..	...
2566	Curtiss	Feb.	5.657	3.939	10	11	− 48.8	− 1.4	+19	2	..	...
2569	Curtiss		7.695	0.244	9	10	− 4.2	+ 0.3	+17	1	..	...
2570	Curtiss		7.707	0.256	13	12	+ 1.7	+ 4.5	+ 6	1	+18	½
2577	Mellor		11.681	4.230	8	8	− 64.8	− 2.7	..	...	..	...
2578	Mellor		11.687	4.235	7	6	− 60.5	+ 1.0	..	...	..	...

TABLE VI. THE ANN ARBOR OBSERVATIONS (Continued).

NO. OF PLATE	OBSERVER	DATE, G. M. T.	PHASE	OSCILLATING LINES NO.	WT.	VEL.	RESID.	K LINE VEL.	WT	H LINE VEL.	WT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	1914	d	d			km.	km.	km.		km.	
2579	Curtiss	12.654	5.202	8	9	− 54.7	+ 5.6	..	...	..	...
2580	Curtiss	12.675	5.223	8	9	− 56.5	+ 3.0	− 9	½	..	...
2585	Curtiss	19.605	0.688	11	10	+ 40.5	− 2.2	+ 20	2	..	...
2588	Curtiss	19.642	0.725	9	10	+ 45.2	− 3.0	+ 12	1	..	...
2589	Curtiss	19.654	0.737	12	13	+ 41.5	− 8.0	..	...	..	...
2599	Mellor	24.672	0.023	7	8	− 20.7	+ 4.0	+ 9	1	..	...
2600	Mellor	24.679	0.030	9	8	− 23.9	+ 0.4	..	...	..	...
2611	Mellor	Mar. 9.612	1.496	8	7	+ 119.8	− 0.2	+ 19	2	..	...
2612	Mellor	9.621	1.505	7	7	+ 129.9	+ 7.8	..	...	..	...
2623	Mellor	11.623	3.507	9	9	− 15.6	− 0.3	− 10	1	..	...
2624	Mellor	11.641	3.525	8	10	− 11.5	+ 5.0	+ 21	1	..	...
2641	Mellor	16.623	2.774	10	8	+ 66.5	+ 2.6	..	...	..	...
2642	Mellor	16.631	2.782	12	11	+ 62.5	− 0.5	+ 14	1	+ 1	1
2649	Curtiss	17.571	3.722	10	11	− 30.1	+ 1.9	+ 18	1	..	...
2650	Curtiss	17.582	3.733	10	9	− 32.6	+ 0.8	+ 10	½	..	...
2655	Curtiss	20.569	0.987	12	12	+ 71.1	− 6.8	+ 15	2	− 8	½
2657	Curtiss	20.599	1.017	10	10	+ 83.8	+ 3.5	..	...	+ 30	1
2659	Curtiss	20.615	1.033	10	9	+ 83.4	+ 0.4	..	...	..	...
2664	Curtiss	Apr. 5.556	5.508	8	9	− 33.4	+ 10.3	..	...	+ 8	1
2665	Curtiss	5.572	5.524	5	4	− 39.4	+ 3.4	..	...	..	...
2666	Curtiss	5.595	5.547	10	10	− 36.9	+ 2.1	..	...	..	...
2670	Curtiss	8.576	2.794	10	8	+ 62.1	− 0.2	+ 28	2	+ 32	1
2679	Curtiss	12.565	1.051	8	10	+ 78.7	− 6.2	+ 10	1	..	...
2689	Curtiss	13.569	2.055	10	10	+ 120.6	− 5.9	..	...	..	...

lengths were corrected by an amount sufficient to reduce to zero the weighted mean of the residuals of each line. These corrected wavelengths are those of column three of Table I.

During the return measures weights were assigned to each line based on the observer's judgment of its availability for velocity determination. With these weights the preliminary velocities for each plate were determined and the wave length correction was determined which reduced to zero the weighted mean of the residuals for each line on all the plates. The final residuals for all of the measures of any line were then employed in the usual way to determine the probable error of a single measurement of that line. The average value of the weights originally assigned to that line was then compared with this probable error and in the cases of five lines it was found that the assigned original weights had been too high or too low by small amounts. On this basis the original weights were corrected, and with this new set of weights the final velocities of column seven, Table VI, were determined. The plate weights in column six are the sums of the weights of the lines from which the corresponding velocities in column 7 were determined.

The normal places of Table VII are based directly on the data of Table VI, the weights, with one exception, being proportional to the sum of the weights of the plates entering into any combination. In the case of the seventh normal place the large residual at once led to suspicion, especially since the agreement among the plates included was very good. It was recognized that a possible explanation for the observed positive displacement of the lines of this normal place might be found in circumstances attending the principal light minimum which occurred within a few minutes of this normal phase. Though the degree of eclipse is small it was thought possible that the interposition of regions of the "atmosphere" of the secondary might produce the displacement observed. On the other hand, Hartmann has two observations near this phase

which, though similarly displaced, exhibit the effect in a considerably smaller degree. Though the first inclination was to omit this normal place from the least square solution because of the uncertainty involved, in view of conflicting considerations, including the absence of a clear case for rejection, it was decided to use the five observations in question with half the normal weight.

TABLE VII. NORMAL PLACES, OSCILLATING LINES.

NO. (1)	PHASE (2) days	LIMITS OF PHASE (3) d d	VEL. (4) km.	RESID. (5) km.	WT. (6)
1	0.023	0.01 to 0.03	− 24.03	+0.83	0.41
2	0.250	0.24 to 0.26	− 0.99	+2.87	0.39
3	0.696	0.63 to 0.74	+ 40.58	−4.20	0.79
4	0.983	0.91 to 1.02	+ 78.12	+0.90	0.61
5	1.073	1.03 to 1.11	+ 85.50	−1.29	0.70
6	1.500	1.49 to 1.51	+124.84	+2.88	0.23
7	1.706	1.66 to 1.77	+132.96	+3.24	0.44
8	2.102	1.95 to 2.21	+124.92	+1.12	0.54
9	2.508	2.42 to 2.56	+ 89.01	−3.69	0.67
10	2.774	2.70 to 2.80	+ 63.09	−1.28	0.56
11	3.109	3.01 to 3.16	+ 32.52	+6.02	0.32
12	3.543	3.50 to 3.60	− 15.39	+2.29	0.56
13	3.727	3.72 to 3.74	− 31.22	+1.86	0.35
14	3.922	3.90 to 3.94	− 50.26	−3.52	0.61
15	4.202	4.15 to 4.24	− 60.03	+1.15	0.49
16	4.302	4.26 to 4.34	− 66.87	−2.04	0.49
17	4.769	4.53 to 4.86	− 70.32	+0.58	0.20
18	5.270	5.20 to 5.32	− 60.01	−2.70	0.98
19	5.514	5.47 to 5.55	− 39.42	+3.86	1.00

From a preliminary solution these approximate elements were adopted:

$$
\begin{aligned}
P &= 5.73248 \text{ days},\\
e &= 0.100,\\
\omega &= -0^\circ.70,\\
T &= 1913, \text{ Sept. } 13.2203,\\
K &= 101.00 \text{ km.},\\
V_0' &= +30.00 \text{ km.}
\end{aligned}
$$

The normal equations are:

$$
\begin{array}{llllll}
+10.34\,\Gamma & & & & & \\
-1.461\,\kappa & -0.858\,\pi & +4.950\,\epsilon & -0.714\,\tau & -2.07 & =0\\
+5.156 & +0.034 & -0.269 & +0.003 & -0.12 & =0\\
 & +5.184 & -0.653 & +4.484 & +0.10 & =0\\
 & & +3.178 & -0.552 & -1.55 & =0\\
 & & & +3.704 & -0.11 & =0.
\end{array}
$$

The values of the corrections are:

$$\delta e = -0.0031,\ \delta\omega = -0^\circ.568,\ \delta T = -0^d.0084,$$
$$\delta K = +0.018 \text{ km.},\ \delta\gamma = +0.19 \text{ km.},$$

and the *final elements* with probable errors are:

FINAL ELEMENTS, δ ORIONIS (ANN ARBOR)

$$
\begin{aligned}
P &= 5.732448 \pm 0.000{,}015 \text{ days}, \quad \text{Epoch, 1908,}\\
e &= 0.0969 \pm 0.00856,\\
\omega &= 358^\circ.73 \pm 1^\circ.92,\\
T &= 1913, \text{ Sept. } 13.2119 \pm 0.0760 \text{ days},\\
K &= 101.02 \pm 0.76 \text{ km.},\\
\gamma &= +20.09 \text{ km.},\\
a \sin i &= 7{,}926{,}000 \text{ km.},\\
m_1^3 \sin^3 i/(m_1+m)^2 &= 0.605\,\odot.
\end{aligned}
$$

The residuals for the normal places based on these elements are found in the fifth column of Table VII. The difference between any residual as computed from the observation equations and from the final elements in no case exceeds 0.04 km. From these residuals the probable error of a normal place of weight one is found to be ± 1.66 km. The residuals for the individual plates as scaled approximately from the velocity curve are given in the eighth column of Table VI. On the basis of these residuals, the probable error of an average plate is found to be ± 3.7 km.

The final period given above was obtained by superposition of the Ann Arbor and Potsdam curves, both of which had been computed with the same preliminary value of the period, $P =$ 5.73248 days. This superposition showed that the average phase difference between the two curves was 0.023 days which is the phase error introduced by using the assumed period over an interval of 11 years and 3 months or 716 orbital periods, from 1902, June, to 1913, September. To remove this phase error a correction of −0.000,032 days ± 0.000,015 days must be applied to the assumed period, the probable error being estimated. A comparison of this final apparent period with that of Hartmann for Epoch, 1898 ± (P = 5.7325 ± 0.000,2 days) indicates that no changes have been established in this quantity by observations covering twenty-five years.

The velocity curve corresponding to my final elements is drawn in the lower figure of Plate

XX. To show at a glance the chief differences between the Potsdam and Ann Arbor curves, part of the latter is compared directly with the former in the dotted line curve of the upper figure. Where the dotted line is not drawn the coincidence is too close to be shown in this manner. Thus it will be seen that these two curves fit together with discrepancies nowhere greater than about 2.5 kms., which is very nearly the probable error of a good normal place. Considering the separate elements it is evident that they do not differ by amounts greater than the uncertainty of the determinations as indicated by the probable errors. No changes are indicated in the orbit of this system.

If the evidence given above, indicating a ratio of the masses of 1.8, be accepted, the values of $m \sin^3 i$ and $m_1 \sin^3 i$ become respectively, 0.81 and 1.46 times that of our sun. Since the bodies involved eclipse each other during their orbital revolution, it is probable that the factor, $\sin^3 i$, is greater than one-half.

Whenever available, the H and K lines have been measured at least once on all of the Ann Arbor spectrograms. The resulting velocities with their weights are given in the last four columns of Table VI. Because of the interference of the close Hϵ line only the simple weighted mean of the H line velocities has been derived. This proves to be $+17 \pm 2$ km.

TABLE VIII. NORMAL PLACES, THE K LINE.

NO. (1)	PHASE (2)	LIMITS OF PHASE (3)	VEL. (4)	RESID. (5)	WT. (6)	INTENSITY (7)
	days	d d	km.	km.		
1	0.065	5.6 to 0.3	+11.0	−1.5	0.5	2.8
2	0.924	0.6 to 1.1	+15.3	+2.8	0.6	3.2
3	1.229	1.1 to 1.5	+15.0	+2.5	0.6	2.3
4	1.930	1.6 to 2.3	+13.0	+0.5	0.5	3.3
5	2.769	2.5 to 3.2	+16.9	+4.4	0.4	2.7
6	3.265	3.1 to 3.7	+ 7.1	−5.4	0.6	3.2
7	3.864	3.7 to 4.0	+12.9	+0.4	0.6	3.5
8	4.256	4.1 to 4.4	+13.0	+0.5	0.9	2.7
9	5.322	4.8 to 5.6	+10.8	−1.7	1.0	3.0

Mean Velocity $+12.5 \pm 0.7$. Mean Intensity 3.0

The velocities for the K line are combined into normal places in Table VIII. and are plotted as full circles in the lower figure of Plate XX. As no variation is established in these velocities, a straight line corresponding to the mean velocity of $+12.5 \pm 0.7$ km. is drawn through them. This mean velocity, which is based on Rowland's wave-length of λ 3933.825, falls 7.6 km. below the velocity of the center of mass of the system. Hartmann's mean velocity for this line ($+16 \pm 1.2$ km.) based on a wave-length which is not given, falls 6.1 km. below his velocity for the system. Apparently, so far as comparison is possible, these results are in substantial agreement. Furthermore, Hartmann's conclusion, which must be construed within limitations, that the K line in the spectrum of δ Orionis does not participate in the oscillatory motion of the other lines, is here borne out in greater degree and extended to the H line. As pointed out by Hartmann these velocities for the fixed H and K lines differ but little from the velocity of the solar system in this direction ($V = +18$ km.), but this observation seems to apply equally well to the velocity of the system of δ Orionis, as we might expect in the case of a Class B star.

ϵ ORIONIS.

THE TOTAL LIGHT.

The visual magnitude of ϵ Orionis ($\alpha = 5^h 31^m$, $\delta = -1° 16'$) as given in the Revised Harvard Photometry is 1.75. Apparently no variation of its brightness has been found, and this star has been used frequently as a comparison star in the study of the light variations of other objects.

THE SPECTRUM.

Epsilon Orionis is a typical star of Class B. An excellent reproduction of its objective prism spectrum is found in *Harvard College Annals*, Volume 28, Plate I; and lists of approximate wave-lengths, with accompanying intensities, for the spectrum lines are found in Tables XXIII and XXIV of the same volume. A detailed record of the lines in this spectrum will be found in a "Catalog of 470 of the Brighter Stars" published by the Solar Physics Committee in 1902.

The wave-lengths resulting from the Ann Arbor measures are listed in Tables I and II, to which sufficient allusion has perhaps been made.

However attention might be called to the Carbon (?) group at λ 4649.5. On two-thirds of the plates of ε Orionis and on about 14 per cent of those of δ Orionis this group was measured as double. In ρ Leonis, of more advanced spectrum, it appears to be single and in practically the same position. It is suggested that this line is reversed in δ and ε Orionis. Reference might be made also to the presence of D1 and D2 in the spectrum of ε Orionis. It would be of importance to know whether these lines regularly accompany the sharp K line in Class B stars and exhibit the same behavior. In certain Novae this is known to be the case at some stages at least. The presence in the spectrum of ε Orionis, of dark lines in the positions of the D lines, was referred to by Campbell in 1894, who gives also a list of lines in δ and ε Orionis. [See *Astronomy and Astrophysics,* Vol. XIII, page 395.]

In commenting on the case of ε Orionis in the course of a three-prism study of twenty Orion stars, Frost and Adams remark, "All of the lines in its spectrum are extremely broad and ill-defined, and the accuracy of measurement is probably less than for any other star in the list." The lines in the spectrum of ε Orionis, though of poor quality, are, nevertheless, much superior to those in the spectrum of δ Orionis. The probable error of a single velocity determination from the best line (Hγ) as measured on the Ann Arbor plates of δ Orionis was ± 7.2 km.; from the average line, about ± 10 km. For ε Orionis these quantities were ± 3.4 km. for the best line and about ± 6 km. for the average line. In many cases emission is present on both edges of absorption lines in ε Orionis and this serves to define these edges more clearly.

Former Radial Velocities.

Three early Potsdam velocities of ε Orionis with a range of 6.4 km. give a mean velocity of + 26.7 km. for the epoch, 1889.00. Four velocities of this star derived by Frost and Adams from spectrograms made with the Bruce Spectrograph during seven months following the date, 1901, Sept. 4, have a range of 2 km. and a mean value exactly in accord with that obtained at Potsdam twelve years earlier.

Fourteen velocities determined by Dr. O. J. Lee with single prism dispersion at Yerkes Observatory from spectrograms made during five years following 1903, Dec. 6, have a range of 21 km. and a mean value of + 27.8 km. The probable error of a single plate velocity on the basis of this mean is ± 3.7 km. which is too large to be accounted for by accidental errors. Frost has announced this star as a spectroscopic binary. Velocities from the narrow and sharp H and K lines, obtained for ten of these plates, give a mean of + 28 km. Though these H and K velocities differ either way from the velocities obtained from the broad lines by 6 km. on the average, Frost infers that these H and K lines share in the oscillations of the broad lines.

The Ann Arbor Radial Velocities.

The thirty Ann Arbor velocities from plates made on seventeen nights in 1913 to 1914 are given with necessary details in Table IX. The reduction including the weighting of lines, was carried out exactly as in case of δ Orionis. The weighted mean of the velocities from the broad lines in column four is + 25.6 km. ± 0.6 km. The residuals from this mean for each of the plates is found in column eight of the table. On the basis of these residuals the probable error of an average plate is found to be ± 3.7 km., and the mean residual, ± 4.41 km., quantities in very close accord with those deduced from Lee's results. Also the range of 18 km. is but three kilometers less than that shown by Lee's measures; and the mean of my measures is in accord with that obtained by all previous observers, within the limits of error of measures of spectra of this type.

In one or two ways it is possible to show that the probable error and mean residual for a single plate, derived above, are larger than we should expect. If ϵ_1 denote the average probable error of a plate deduced from the internal agreement of the velocities from the several lines of the plates of a given star of constant velocity; and if ϵ denote the probable error of a plate deduced from the comparison of velocities from these several plates of the same star; and, finally, if ϵ_2 denote that element of the probable error of a

TABLE IX. VELOCITIES OF ϵ ORIONIS.

NO. OF PLATE	OBSERVER	DATE, G. M. T.	BROAD LINES					K LINE		H LINE	
			VEL.	NO.	WT.	P. E.	RESID.	VEL.	WT.	VEL.	WT.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10	(11)	(12)
		1913 d	km.			km.		km.		km.	
1606	Curtiss	Feb. 8.705	+21.6	13	29	±1.3	−3.9	+24	1	..	...
1607	Curtiss	8.717	+28.0	14	17	1.4	+2.5	..	.	..	...
2422	Curtiss	Nov. 1.815	+27.7	13	18	1.8	+2.2	+22	2	+12	1
2423	Curtiss	1.822	+24.4	16	26	1.2	−1.1	+12	2	+14	1
2481	Mellor	Dec. 10.739	+30.2	16	20	1.3	+4.7	+20	2	+12	1
2482	Mellor	10.753	+30.0	14	20	2.5	+4.5	+12	2	..	...
2499	Merrill	14.698	+16.8	16	23	1.2	−8.7	+11	2	..	...
2514	Curtiss	18.845	+28.3	10	15	1.3	+2.8	+16	1	..	...
2515	Curtiss	18.855	+33.2	12	12	1.5	+7.7	..	.	..	...
2540	Mellor	1914 Jan. 13.725	+32.1	12	20	1.1	+6.6	+ 6	1	..	...
2541	Mellor	13.732	+33.1	6	6	2.7	+7.6	+14	1	..	...
2567	Curtiss	Feb. 5.676	+23.3	10	15	3.7	−2.2	+15	1	..	...
2568	Curtiss	5.695	+27.8	16	20	1.9	+2.3	+15	1	+ 5	½
2571	Curtiss	7.733	+26.9	20	27	1.0	+1.4	+20	1	..	...
2581	Curtiss	12.692	+28.8	19	31	1.5	+3.3	+ 1	1	+10	½
2582	Curtiss	12.706	+26.7	14	19	1.9	+1.2	+ 3	2	..	...
2590	Curtiss	19.670	+15.7	20	29	1.3	−9.8	+ 5	1	..	...
2639	Mellor	Mar. 16.592	+19.1	13	20	1.4	+6.4	+21	2	+20	½
2640	Mellor	16.610	+21.2	12	23	2.2	−4.3	+20	1	+28	½
2647	Curtiss	17.549	+24.1	18	25	0.9	−1.4	+23	2	+ 2	½
2648	Curtiss	17.561	+26.8	17	25	1.5	+1.3	+13	1	+31	1
2651	Curtiss	17.601	+29.3	19	28	1.6	+3.8	+17	2	+28	½
2654	Curtiss	20.562	+21.2	16	24	0.9	−4.3	± 0	1	..	...
2656	Curtiss	20.590	+17.0	17	28	0.7	−8.5	+14	1	..	...
2658	Curtiss	20.607	+22.1	20	26	0.8	−3.4	+32	1	..	...
2667	Curtiss	Apr. 5.605	+30.4	20	26	1.7	+4.9	..	.	..	...
2668	Curtiss	5.617	+31.5	13	15	2.0	+6.0	..	.	..	...
2671	Mellor	8.583	+31.2	15	17	2.2	+5.7	+43	1	+21	1
2680	Curtiss	12.577	+33.5	15	22	1.5	+8.0	+13	1	..	...
2690	Mellor	13.579	+27.5	13	19	1.4	+2.0	..	.	..	...
Means			+25.6 ± 0.6 km.					+17.0 ± 2.5 k		+15.6 ± 1.2 km.	

given average plate which is introduced by causes other than those contributing to ϵ_1, we may write,

$$\epsilon^2 = \epsilon_1^2 + \epsilon_2^2.$$

The last quantity, ϵ_2, will depend largely upon systematic spurious displacements of the star and comparison spectra due to instrumental errors, variations in personal equation, systematic asymmetry of lines, etc. For different sets of plates made with a given spectrograph and measured by experienced observers, this element of the probable error of a single plate should be approximately constant. On the other hand, ϵ_1 will depend largely upon the relative accuracy of the wave-lengths and the measurability of the star lines.

From twenty plates of α Lyrae's spectrum, made here and measured by Mr. L. L. Mellor, it is found that

$$\epsilon = \pm 1.74 \text{ km.},$$
$$\epsilon_1 = \pm 1.45 \text{ km.},$$

and thus

$$\epsilon_2 = \pm 0.97 \text{ km.},$$

which is probably a little greater than the average value of this quantity.

Combining this value of ϵ_2 with the value of ϵ_1 (= ± 1.6 km.) found above for ϵ Orionis in Table IX, column 7, we deduce the value, ± 1.9

km., for the probable error (ϵ) of the velocity from a single spectrogram of this star. Further this same value for ϵ Orionis is obtained from differences between velocities from pairs of plates of this star made in rapid succession on the same night, the only assumption being that the velocity does not vary appreciably during the short interval involved.

In the light of this value for the probable error of a single plate velocity of ϵ Orionis it is apparent that the excessive magnitude of this quantity as deduced from the velocities of Table IX is attributable to the variable velocity of this star.

A good idea of the extent of the variation of the radial velocity of ϵ Orionis may be secured if we assume that this variation follows a sine curve with the forty-four velocities determined by Lee and the writer uniformly distributed along the time axis. For, if K represents the half amplitude of the assumed sine curve, the average of the absolute values of a large set of velocities distributed evenly along the time axis will be very nearly,

$$\frac{K\int_0^{\pi} \sin x \, dx}{\int_0^{\pi} dx},$$

which equals $2K/\pi$. This is the average quantity which enters into the residuals in column eight of Table IX as the result of the assumed velocity oscillation. Accordingly the element of the probable error of a single plate due to this effect upon these residuals is approximately $\pm\ 1.75K/\pi$, on the basis of the well known shorter formula for probable errors. Calling this ϵ_3, and the probable error of a single plate velocity based directly on the residuals in column 8 of Table IX, E, we may write,

$$E^2 = \epsilon^2 + \epsilon_3^2,$$

from which we derive a value for K of 5.7 km. and a velocity range of 11.4 km. This is probably only an approximate value of the velocity range, however, for the frequency curve of the Yerkes and Ann Arbor velocities of this star indicates an orbital eccentricity of about 0.3.

The range of variation of ϵ Orionis is so small that it is not strange that considerable difficulty has been experienced in finding a satisfactory period. If we plot along the time axis the twenty-eight velocities observed at Ann Arbor during the past winter (1913-1914), they at once suggest a sine curve with the elements: Period = 100 days, $K = 13$ km., $V = +26.5$ km. But the probable error of a single observation as based on the residuals from this curve is $\pm$ 2.6 km. which is still too large, though greatly reduced. Probably this apparent adherence to a long period variation is partly accidental but it certainly suggests some interesting commensurability of the true, and probably short, period with the day.

In writing an expression which shall connect the long period with some short period which shall be very nearly equal to some round fraction of a day, we may let p represent the long period; P, the short period; a, the rounded value of $1/P$; and dT, the interval by which the average hour of observing changes toward smaller values during the series of plates. Then

$$P = \frac{p - dT}{ap \mp 1}$$
$$= (\text{approx.})\ \frac{1}{a} \pm \frac{1}{a^2 p} - \frac{dT}{ap}.$$

On the basis of these formulae and the value of 100 days for p, a number of different periods have been derived and tested. Of these the best are 0.49677 days and 0.33173 days. The observations when plotted with these periods suggest a sine curve with an amplitude of about ten kilometers with an average residual little if any smaller than that derived from the long period oscillation. On the whole it seems probable that further search for a period might better wait until more observations are available. An explanation, which usually is suggested when a small velocity range of short period is found in an early type star, might be offered here; namely, that the lines in this spectrum are really composite though never resolved. Under these circumstances, if the two components be of unequal brightness, capricious changes depending on the density of the

spectrogram might be measured in the positions of the lines.

In a set of preliminary reductions of the measures of the Ann Arbor spectrograms of ε Orionis, the H and K lines were included with the others in the mean velocity. When it became evident that these two lines were consistently displaced in the direction of shorter wave-lengths with reference to the other lines, the measures of them were segregated and collected with assigned weights in the last four columns of Table IX.

The weighted mean of the twenty-five velocities derived from the K line is $+ 15.6 \pm 1.2$ km., a result 9.5 km. less than the mean velocity derived from the broad lines on these same plates. The weighted mean of the eleven velocities from the H line is $+ 17.0 \pm 2.5$ km., a result 9.2 km. less than the mean velocity obtained from the broader lines on the same plates. It is interesting to observe that the final mean velocity from the calcium lines (+ 16.0 km.) is less than all but one of the plate velocities determined from the broader lines. It is also pertinent to note that the velocity from the K line in δ Orionis falls 7.6 kms. below the velocity of that system as deduced from the oscillating lines.

It remains to consider whether the displaced calcium lines follow the broader lines in their oscillations. If the calcium lines do oscillate in parallel with the broader lines it would be expected that the differences between the broad line velocity and that from the calcium lines of each plate would agree for the series better than do the calcium line velocities among themselves. However the reverse is the case. The average residual of the differences, broad lines minus calcium lines, from their mean is ± 6.7 km., which is reduced to ± 6.5 km. by taking into account the probable error of the broad line velocities, whereas the average residual of the calcium line velocities from their mean is ± 5.8 km. This is, within reasonable limits, the result which we would anticipate if the calcium lines were fixed and the broad lines were oscillating with a range of about 10 km., which is roughly the range of variation of the broad line velocities deduced above. In the case of the Yerkes Observatory velocities, the average difference between the broad line velocities and those from the calcium lines of each plate is ± 5.8 km. which is reduced to ± 5.6 km. by taking into account the probable error of the broad line velocities. At the same time the average residual of the calcium line velocities from their mean is ± 5.2 km., a difference in fair agreement with the Ann Arbor results. There seems to be little or no evidence to indicate that the calcium lines oscillate with the broad lines in ε Orionis.

The interesting difference of 12 km. between the mean velocity deduced from the calcium lines at Yerkes Observatory and that observed at Ann Arbor, only two km. of which is attributable to systematic discrepancy, may indicate a variation of the velocity derived from the H and K lines—possibly a variation of long period.

If we accept Hartmann's highly interesting hypothesis of a calcium cloud lying between the sun and certain stars in the constellation of Orion, the Ann Arbor measures furnish the following determinations of the radial velocity of this calcium medium with reference to the sun:

STAR	LINE	VELOCITY km.	WEIGHT
δ Orionis	K	+ 12.5	8.0
	H	+ 17.2	1.0
ε Orionis	K	+ 15.6	3.0
	H	+ 17.0	0.6

Velocity of calcium cloud, + 13.8 km.

In view of the importance of comparison among determinations of this "calcium cloud" velocity at different epochs and with different instruments, it may be said that the presence of excellent *H* and *K* bright lines in the comparison spectrum of many of the Ann Arbor spectrograms of ε and δ Orionis has enabled the writer to check within a kilometer by direct measures the velocities from these lines as derived through the use of Rowland's wave-lengths.

SUMMARY.

The foregoing paper is devoted more particularly to a discussion of the total light, spectra and radial velocities of δ and ε Orionis. The investigations reported in the present paper include: a definitive determination of the elements of the orbit of δ Orionis from the Potsdam radial

velocity observations of Hartmann; a study of the character and a determination of the wave lengths of the measurable lines between $H\zeta$ and $H\alpha$ on 74 spectrograms of δ Orionis and 30 spectrograms of ϵ Orionis, made at the Detroit Observatory during the last three years; and studies of the radial velocities determined from these 104 spectrograms.

The principle results of this study are:

1. No certain changes are found in the spectrum of δ Orionis in a period of eleven years.

2. The wave-lengths, which were determined in this paper for all measurable lines, show interesting divergence from the assumed values, the most striking of which is that for the $H\delta$ line.

3. Some indication is found of lines of a secondary star with a mass 1.8 times that of the primary.

4. Little relation is indicated between phase and structure changes of lines in the spectrum of δ Orionis.

5. The results from least square solutions of 37 observations of δ Orionis by Hartmann at Epoch, 1902, June, and 74 observations at the Detroit Observatory at Epoch, 1913, Sept., establish no changes in the velocity curve in the interval of 11 years.

6. An improved apparent orbital period $5.732448 \pm 0.000{,}015$ days is derived together with other new definitive elements of the orbit of δ Orionis.

7. No certain oscillation with the broader lines is found in the case of the sharp H and K lines in δ Orionis and, using Rowland's wave-lengths, the average displacement of these sharp lines from the normal position of the oscillating lines is seven kilometers negative.

8. The D lines of sodium are seen in the spectrum of ϵ Orionis but are probably too narrow to be observed in the spectrum of δ Orionis with the dispersion employed.

9. Clear evidence of the velocity variation as announced by Frost is recognized in the Ann Arbor measures of the spectrum of ϵ Orionis. The velocity range indicated is about 11 km.

10. A provisional period of 100 days is suggested for the velocity oscillations of ϵ Orionis and shorter periods derived from this are given.

11. The conclusion is reached that the H and K lines of calcium on the Ann Arbor spectrograms of ϵ Orionis probably do not oscillate in parallel with the broader lines and are displaced negatively about nine kilometers with respect to the mean velocity for the other lines.

12. A comparison of the Ann Arbor velocities for the H and K lines with corresponding velocities determined at the Yerkes Observatory for an earlier epoch suggests a variation in the position of these lines.

13. Assuming with Hartman a calcium cloud between us and these Orion stars, the radial velocity of this medium is found to be + 14 km. per second referred to the sun.

Ann Arbor, Mich., July 24, 1914.

THE SPECTRUM AND RADIAL VELOCITY OF ψ PERSEI AND OF THE BRIGHTEST COMPONENT OF β MONOCEROTIS

By PAUL W. MERRILL

The bright-line stars, ψ *Persei* and β *Monocerotis* (brightest preceding component) were placed by the writer in the ϕ *Persei* group[1] of stars of class B having bright hydrogen lines. The type star, ϕ *Persei,* is a spectroscopic binary which has been studied extensively by several observers,[1,2] and found to possess a very complex and interesting spectrum, which varies synchronously with the orbital period. The changes are, however, not exactly repeated in different revolutions. The orbit appears to be non-elliptical.

The hydrogen lines of ψ *Persei* and of β *Monocerotis* consist each of a strong, well-defined dark line flanked on either side by bright borders which are very strong at Hβ, less marked at Hγ, and at succeeding lines are so weak as to be inconspicuous or apparently absent, leaving only a sharply defined absorption line. In some cases absorption is seen outside of the bright portions. The velocities recorded in this paper as derived from the hydrogen lines depend on the central absorption, but those given by the mean of the two bright components, where measurable, are nearly the same. In other words, the emission is practically symmetrical on either side of the central dark line. 4101.98 A was taken as the wave-length of Hδ; Rowland's wave-lengths were used for the remaining hydrogen, and calcium lines. The wave-lengths for the titanium comparison lines were those determined by Mr. Mellor,[3] using the same spectrograph with which the stellar plates were secured. This is a single-prism instrument, described in Vol. I, p. 38, of these Publications.

The present observations reveal no *certain* change in any feature of the spectrum of either star. Apparent changes in the broad outside absorption of the hydrogen lines were recorded by Miss Maury.[4] Such changes might be suspected from my plates but could scarcely be established. The wide objective prism spectra probably give evidence of greater weight on this point than do slit spectrograms.[5]

The chromospheric (enhanced metallic) lines Fe 4584.10 A, and Co, Ti 4629.52 A are present in both spectra, as in ϕ *Persei,* as faint, bright-edged absorption lines. Broad and weak absorption lines of helium are present, and Mg 4481 A, of the same character. Other notes are given in the remarks following each table.

ψ PERSEI.

($\alpha = 3^h\ 29^m.4$; $\delta = +47°\ 51'$; Mag. = 4.3; Class B 5 p).

TABLE I.

DATE G.M.T.	RADIAL V.	SEPARATION Hβ	SEPARATION Hγ	RATIO
1	2	3	4	5
1911 Oct. 2.820	+0.2 km.	3.26 A		
13.722	−3.4	3.76		
18.789	−0.4	3.70		
22.738	−0.6	3.40		
27.762	−0.9	3.40	2.83 A	1.20
Nov. 25.762	+4.1	3.27	2.77	1.18
29.720	+3.5	3.36		
29.748	+4.0	3.61		

[1] *Lick Observatory Bulletins, 7,* 162, 1913.
[2] Cannon, *Jour. R. A. S. Can., 4,* 195, 1910.
Ludendorff, *A. N., 168,* 17, 1910.
Jordan, *Pub. Allegheny Obs., 3,* 31, 1913.
[3] *Publ. Observatory, Univ. of Mich., 1,* 140.
[4] *Annals H. C. O., 28,* 104, 1897.
[5] Ibid., *56,* 263, 1912.

	Dec.	5.754	—2.9	3.32	2.95	1.12
		5.767	+2.8	3.67		
1912	Oct.	12.750	—3.7	3.42		
		13.726	—0.9	3.42		
	Dec.	14.665	+1.0	3.54		
1913	Jan.	12.663	—2.5	3.62	2.66	1.36
	Oct.	9.709	0.0	3.79	2.92	1.30
		9.742	—4.7	3.49		
		11.718	—0.7	3.71		
		12.757	—1.1	3.54		
		25.755	—0.4	3.30		
		31.723	+2.3	3.31		
	Nov.	1.711	+1.4	3.50		
Mean		1912.7	—0.1±0.37	3.49±0.03	2.83±0.04	1.23±0.03

Columns three and four, headed "Separation" give the measured distance between the two bright maxima of the line indicated. Column five gives the numerical ratio of the numbers in column three to the corresponding numbers in column four.

All of the plates were taken by Curtiss (who kindly turned them over to the writer for discussion) except that on 1913 Oct. 11 by Mellor, and that on 1913 Oct. 31 by Merrill.

There is no evidence of variation in radial motion. The probable error of the velocity from a single plate is ± 1.7 km. K is an absorption line, well-defined, though not very narrow. Measured on 9 plates, it yields a velocity of + 1.6 ± 1.1 km., being accordant with that from the hydrogen lines. On several plates a weak line is seen in the position of H. On the first plate of 1911 Dec. 5 the separation of the bright portions of 4629 A was measured as 2.9 A.

β MONOCEROTIS—BRIGHTEST COMPONENT.

($\alpha = 6^h\ 24^m.0$; $\delta = -6°\ 58'$; Mag. = 4.7; Class B 3 p).

TABLE II.

DATE G.M.T.			RADIAL V. (HYDROGEN LINES)	SEPARATION Hβ	SEPARATION Hγ	RATIO
1			2	3	4	5
1913	Oct.	31.794	+22.0 km.	3.90 A		
	Nov.	16.775	+20.8	3.74		
	Dec.	14.781	+21.5	3.84		
1914	Feb.	1.680	+24.6	3.92	3.19 A	1.23
	Mar.	19.556	+21.8	4.23	2.52	1.68
	Oct.	30.916	+22.3	4.34		
	Nov.	1.802	+24.2	3.88	2.69	1.44
		1.865	+22.3	3.75		
		22.800	+21.9	4.15	2.80	1.48
		22.849	+21.3	4.00	3.07	1.30
		27.764	+23.5	3.87	2.82	1.37
Mean		1914.5	+22.4±0.25	3.97±0.04	2.85±0.07	1.42±0.04

There is no evidence of variation in radial motion. The probable error of the velocity from a single plate is ± 0.84 km. Five three-prism spectrograms taken at Lick Observatory during the years 1905 to 1912 gave a mean value of + 21.6 km. for the radial velocity.[1]

[1] *Lick Observatory Bulletins*, 7, 162, 1913.

The following table summarizes measures of additional lines on the present series of plates of *β Monocerotis*.

TABLE III.—*β* MONOCEROTIS.

WAVE-LENGTH	RADIAL V.	NO. OF PLATES	SEPARATION OF BRIGHT COMPS.	NO. OF PLATES
1	2	3	4	5
4584.10 Fe	+18.5	4	4.2	2
3933.82A(K)	+22.6 km.	6		
3968.62 (H)	+22.8	2		
4233.40 Fe, Cr	+20.4	3	4.2 A	1
4629.52 Co, Ti	+28.3	3		

Table IV shows mean values of the separation for several of the more important of the double bright lines in the photographic region, as measured by the writer.

TABLE IV.

SEPARATION OF BRIGHT COMPONENTS.

STAR	Hβ	Hγ	RATIO	4584 A	4629 A
1	2	3	4	5	6
φ Persei	4.1 A	3.5 A	1.2	3.8 A	4.2 A
ψ Persei	(3.2) 3.49	2.83	1.23		2.9:
β Monocerotis	(3.7) 3.97	2.85	1.42	4.2	

The figures in parentheses, and all those for *φ Persei* were obtained at Lick Observatory.

GENERAL REMARKS.

The three groups of bright-line spectra of Class B, designated by the names of the typical stars, *γ Cassiopeiae*, b² *Cygni*, *Electra*, seem to form a series, the progression being a decrease in strength of the bright portions of the hydrogen lines, and a strengthening, or a widening, of the central absorption. In this connection the *φ Persei* group is anomalous, having intense bright lines, and strong, wide central absorption. The features distinguishing this group from the *γ Cassiopeiae* group are the strong central absorption, the sharply cut inner edges of the bright portions, and the strength of the bright chromospheric lines. It seems probable that these features are the result of vigorous atmospheric activity, which produces more marked absorption (reversal) as well as intense bright lines. The hydrogen lines in this group resemble closely in appearance the self-reversed lines of the electric arc. Since cool or non-ionized hydrogen seems incapable of selective absorption, this may be construed as an argument for the intense conditions just referred to; so that if this group of stars is to be put in a series with the others, it should probably come first.

ANN ARBOR, FEB., 1915.

THE RADIAL VELOCITY OF MAIA

By PAUL W. MERRILL

Maia (20 Tauri; $\alpha = 3^h\ 39^m.9$; $\delta = +24°4'$; Mag. = 4.8; Class B 5) was announced as a spectroscopic binary by Adams[1] in 1904. It was on this account placed on the observing program here in the fall of 1912 by Dr. Curtiss. Since then 44 plates have been secured with the one prism spectrograph,[2] of which 40 have recently been measured by the writer. The emulsion of 33 plates is Seed 23; of 7, Red Label Lantern Slide.

Little evidence of variation in the radial motion has appeared from this series. The total range is 19.5 km., and with the exception of one plate, 16.0 km. The number of lines available for measurement is small, and although they are of fair quality, especially for this class of spectrum, they are not the best. The accuracy of the actual *measurement* may be inferred from the fact that in the repetition of measures on 7 plates the greatest divergence is 3.3 km., and the average divergence 1.7 km. But, as every line-of-sight observer realizes, this unfortunately does not represent the accuracy of the deduced radial velocity.

[1] *Ap. J.*, *19*, 341, 1904.

[2] This volume, p. 37.

RADIAL VELOCITY OF MAIA.

DATE		G. M. T.	NEGATIVE BY	VELOCITY	LINES*	WT.
1912	Oct.	4.863	Mellor	+ 10.4	6	..
		5.746	Lindsay Curtiss	+ 12.6	6	..
		5.765	Lindsay	+ 3.4	4, 6	..
		5.800	Lindsay	+ 11.2	6	..
		6.750	Curtiss	+ 11.4	5	..
		7.864	Mellor	+ 13.1	4	..
		13.793	Curtiss	+ 7.6	5	½
		16.820	Mellor	+ 1.5	4	½
		25.860	Mellor	+ 3.6	4	..
		26.785	Lindsay	+ 13.9	5, 5	..
		26.799	Lindsay	+ 9.2	5	..
		26.809	Curtiss	+ 4.3	5, 5	..
	Nov.	3.799	Curtiss	+ 2.3	4	..
		3.808	Curtiss	+ 9.6	5	..
		10.816	Curtiss	+ 2.1	4	½
		10.829	Curtiss	+ 0.4	4	..
		15.756	Mellor	— 1.7	5	..
		15.767	Mellor	— 5.6	6, 5	..
		22.811	Mellor	+ 4.9	4	..
		27.725	Mellor	+ 9.9	5	..
		29.756	Mellor	+ 7.2	4	..
		29.771	Mellor	+ 8.4	5	..
		30.693	Lindsay	+ 2.0	5, 5	..
		30.714	Lindsay	+ 1.0	4	½
	Dec.	7.582	Curtiss	+ 5.1	5	..
		8.632	Curtiss	+ 9.9	4	½
		8.666	Curtiss	+ 4.7	6	½
		14.697	Lindsay	+ 4.8	4	..
		14.709	Lindsay	+ 12.3	3	..
1913	Jan.	12.718	Curtiss	— 2.1	5, 5	..
		12.739	Curtiss	+ 5.0	5	..
		24.638	Mellor	+ 8.1	5	..
		24.658	Mellor	+ 12.1	7, 5	..
	Feb.	8.619	Curtiss	+ 6.0	5	..
		8.649	Curtiss	+ 10.6	5	..
		17.616	Mellor	+ 6.2	3	..

* Two numbers in this column indicate that the velocity is the mean of two measures.

DATE		G. M. T.	NEGATIVE BY	VELOCITY	LINES	WT.
1914	Feb.	1.524	Merrill	+ 10.2	7	..
		1.567	Merrill	+ 5.8	6	..
		1.597	Merrill	+ 6.0	5	..
		1.622	Merrill	+ 3.4	7	..
Mean:				+ 6.41 ± 0.51.		

Regarding the velocity as constant the probable error of the weighted mean is ± 0.51 km., and of a single plate ± 3.1 km. This is not much larger than would be expected from the internal agreement of the lines of one plate. A plot of the observations seems slightly to indicate a minimum about 1912 Nov. 16, with the possibility of a periodicity in the neighborhood of 55 days, but the evidence is much too weak for certainty. If such a variation exists the double amplitude of the velocity range is probably but little over 10 km. per second, and is scarcely worth attacking at present in view of the many more favorable opportunities presented to the spectroscopist. A very short period is not excluded but has small probability in view of the number and distribution of the observations. The velocity range found by Adams[3] from 7 plates is 28.3 km. Of this 26.1 km. occurs in a period of two days. If a single plate be omitted the range is reduced to 16.3 km.

Using Rowland's wave-length of 3933.825 A for calcium K, the Ann Arbor series gives a velocity from that line, from 32 plates, of + 5.4 km., which does not differ substantially from that yielded by hydrogen and other elements.

March, 1914.

[3] loc. cit.

A STUDY OF THE TITANIUM SPARK AS A COMPARISON SPECTRUM IN THE SINGLE-PRISM SPECTROGRAPH

By LEWIS L. MELLOR

INTRODUCTION.

The purpose of this investigation is to study the wave-lengths of the measurable lines of the titanium spark-spectra as photographed with the single-prism spectrograph of this Observatory, as compared with similar data obtained in the laboratory with instruments of higher dispersion. It is thus hoped to determine the relative reliability of different lines for radial velocity determinations, to adjust the wave-lengths of all measurable lines to a homogeneous system for this instrument and to establish the degree of dependence which may be assumed in connection with the quantitative use of the titanium spark comparison in spectrum investigations with spectrographs of the type here employed.

It is a well known fact that the effective wave-lengths of the lines in the spark comparison of the stellar spectrograph are modified by the blending, especially under low dispersion, of lines due not only to the element used but to impurities in the terminals and to air lines which are present in the spectrum of the spark discharge through air. The detection of the errors in wave-lengths due to these causes requires the study of all the lines available, under different conditions of exposure, to discover variations of individual lines from the laboratory positions.

OBSERVATIONS.

The spectrograph with which the plates were made for this investigation has been fully described in an earlier paper by Dr. Curtiss in this volume. The comparison spectrum employed from the first has been that of the titanium spark between terminals of approximately eighty percent purity, the chief impurities being iron and calcium. The metal used for these terminals was procured from Eimer and Amend. The capacity and self-induction in the spark circuit have been so adjusted as to make the continuous spectrum and air lines relatively faint. The customary ground glass mat, inserted between the two sets of spark terminals and the slit-head, diffuses the continuous spectrum of the core of the spark and renders the intensity of the lines uniform throughout their length.

Twenty-six plates, with the exception of two, were selected for measurement from our observing list of stellar spectra, and may be enumerated and classified as follows: fourteen of medium exposure, the lines in the spectrum of which are numerous and well-defined; five of about twice the medium exposure and seven of about one-half the medium exposure. The plates which are included in each set have nearly the same relative intensity, but most of them were taken under various degrees of temperature, ranging from $+1.4°$ C. to $+29°$ C. With the exception of one on a Red Label Lantern Slide all the spectra were photographed on Seed 23's; the exposure time for the latter plate being on the average about one minute, twice this amount being required for the former.

THE MEASURING ENGINE.

The engine used for the measurement of these plates was designed by Dr. Curtiss and constructed by Messrs. Henry and Emile Colliau in the Observatory Shop. Originally the machine was intended for measurements in two co-ordinates but it has proven equally efficient for those in one. It may be well to mention a few of its interesting features.

The box casting or engine-bed is provided with ball bearings which partially support the weight of the plate carriage and allow it to move very freely in its ways.

The micrometer head, 20 cm. in diameter, is divided into two hundred divisions, which can be easily read to a tenth of a division, so that the movement of the screw can be read to $\mu/2$. The screw is 14 mm. in diameter and approximately

17 cm. in length, with a pitch of one millimeter. Soon after the machine was assembled and adjusted the periodic error for ten revolutions of the screw was determined and found to be 6×10^{-6} of an inch per quarter revolution. Later, during the measures, a different portion of the screw was tested in the same manner as before, but no appreciable deviation from the first determination could be detected.

The revolving plate-holder, intended primarily for the measurement of position angle and the orientation of the plate, is very convenient for reversing the plate and especially so for making its final adjustment.

MATERIAL.

In 1909 Kilby[1] redetermined the wave-lengths of the arc and spark lines of titanium; and the conclusion drawn from his investigations was that no determinable shift existed between them. Accordingly all available wave-lengths, in both arc and spark, were used in obtaining for present use the laboratory values of the wave-lengths of the titanium lines measured on our plates between λ 3748 Å and λ 5064 Å. These wave lengths for the arc and spark of titanium have been tabulated by Dr. Kayser[2] as determined by the following observers: Kilby (arc and spark), Fiebig (arc), Hasselberg (arc), Exner and Haschek (arc and spark), Eder and Valenta (spark), and Lohse (spark). In this list are also included Rowland's observations referred to the solar spectrum. Further, the observations of the enhanced lines of titanium by Reese[3] and Lockyer[4] were used connectively with the above list.

It should be stated however that Kilby's results are expressed on the basis of the International system, but in astrophysical work it has been customary to reduce all observations to Rowland's standard. Thus care was taken to reduce Kilby's observations to the usual standard so that consistency in all results would be maintained. The results of the several observers are in good agreement and certainly within the limits of accuracy required for this work, particularly since our measures are for the determination of relative rather than absolute values. The mean of the observations made by the investigators named above referred to Rowland's standard are found in Table I, column II.

[1] *Astrophysical Journal*, 30, 243-267, 1909.

[2] *Handbüch der Spectroscopie*, 6, 674-689.

[3] Ibid., 19, 322-329, 1904.

[4] Tables of the Wave-lengths of Enhanced Lines in the *Publications of the Solar Physics Committee*, 22-25, 1906.

METHOD OF MEASUREMENT.

On account of the great number of lines studied, each plate was measured in two sections, the first, from λ 3748 to λ 4338, in the forenoon, and the second from λ 4338 to λ 5064, in the afternoon. Each plate was measured twice, direct and reversed, and throughout the reduction each half was treated separately. Six settings were made on each pair of lines, approaching always from the same direction with a speed as nearly constant as possible. Special care was taken in order that no change in illumination should occur during the measures.

REDUCTIONS AND TABLES.

Five lines, selected on the basis of their sharpness and proper spacing on the negative were made use of in computing two sets of constants from the Hartmann interpolation formula

$$\lambda = \lambda_0 + \frac{C}{R_0 - R}.$$

where λ_0, C, and R_0 are constants depending upon the measures, λ represents the assumed wave-lengths and R the corresponding screw readings. The values of the known quantities for three lines occurring on the first half of the plate are

λ	R
3904.960	51.1863
4078.632	64.3706
4338.082	79.9988

and those for the second half

λ	R
4338.082	80.0013
4623.280	93.2674
4981.916	106.0266

Substituting these values of each set independently in the above equation and solving simultaneously, we obtain

$\lambda_0=2240.977$, $R_0=190.6905$, $C=232132.4$,

and

$\lambda_0=2244.017$, $R_0=100.6743$, $C=231756.6$.

The wave-lengths corresponding to the observed screw readings may now be easily computed.

MEDIUM EXPOSED PLATES.

Measures made on the first five plates were reduced to the dispersion of the first plate, and those on the remaining nine plates to the dispersion of the first five. The mean screw readings R, derived from these fourteen plates, were used for the computation of their corresponding wave-lengths λ. It should be stated, moreover, that the mean of the prism temperatures for the first plate was $+13^\circ.7$ C, which is about the average for this Observatory.

With the method of reduction employed, errors that arise in the measurement of the first plate would probably have a disproportionately large effect upon the final results. This supposition was thoroughly tested by taking the straight means of all the previous measures of each line and reducing these mean settings to the same dispersion as above. An opportunity then presented itself for making a comparison between the two different values of R for any line and finally for obtaining the corresponding differences in wave-lengths, which on the average was approximately 0.003 Å, except in one or two instances where the lines were ill-defined. Although the second reduction showed these differences to be very small it seemed best to make use of them for the determination of the mean values of the screw readings and wave-lengths, R_m and λ_m, which are given in Table I, columns 1 and 2. Column 3 contains the probable errors, $P.E.$, in Ångstrom units. Those lines having probable errors large enough to make them unreliable for radial velocity determinations were excluded from the final list.

TABLE I.

Rm (1)	λm (2)	P. E. (3) ±	RM (4)	λM (5)	P.E. (6) ±	λo—λm (7)	λu—λm (8)	CURTISS (9)	SCHLESINGER & BAKER (10)	ROWLAND'S STANDARD (11)	REMARKS (12)
36.6670	3748.121	0.0048	36.6660	3748.111	0.0041	—0.026				3748.181	P 1
37.1598	3752.985	0.0030	37.1592	3752.979	0.0022	—0.024	+0.006	3753.057		3753.017	G 6
37.6559	3757.879	0.0039	37.6557	3757.877	0.0033	—0.004				3757.836	F 3
37.8120	3759.428	0.0028	37.8120	3759.428	0.0021	+0.010	—0.007	3759.418		3759.449	G 9
38.0152	3761.440	0.0066	38.0160	3761.456	0.0048	+0.019	+0.001	3761.410		3761.469	G 10
39.0470	3771.782	0.0052	39.0468	3771.780	0.0045	—0.004				3771.809	P 0.3
40.4654	3786.220	0.0033	40.4655	3786.221	0.0028	+0.005		3786.188		3786.188	F 0.8
43.1900	3814.752	0.0056	43.1900	3814.752	0.0048	—0.001		3814.722		3814.723	F 0.5
48.6691	3875.441	0.0078	48.6689	3875.439	0.0067	—0.007				3875.434	F 0.5
49.2995	3882.724	0.0052	49.2999	3882.729	0.0038	±0.000	+0.010	3882.678			F 3 Br Bl(2 lines)
50.8328	3900.720	0.0054	50.8329	3900.721	0.0040	+0.009	—0.004	3900.672		3900.711	G 8
51.1864	3904.926	0.0061	51.1868	3904.931	0.0045	±0.000	+0.010	3904.942		3904.960	G 3
51.9127	3913.630	0.0054	51.9126	3913.629	0.0044		—0.002			3913.640	F 4 Br.
52.5695	3921.582	0.0036	52.5690	3921.576	0.0031	—0.016				3921.584	F 1
52.8239	3924.684	0.0052	52.8240	3924.686	0.0038	±0.000	+0.003	3924.663	.672	3924.687	G 2
53.2595	3930.015	0.0028	53.2592	3930.011	0.0024	—0.012		3930.041	.037	3930.026	G 1.5
53.4329	3932.147	0.0050	53.4331	3932.149	0.0043	+0.008				3932.188	G 1.2
54.7032	3947.946	0.0067	54.7063	3947.987	0.0055		+0.082			3947.924	G 1
54.7759	3948.857	0.0070	54.7754	3948.851	0.0057		—0.011			3948.825	G 3
55.3813	3956.498	0.0044	55.3808	3956.492	0.0032	—0.012	—0.003			3956.479	G 3

Rm (1)	λm (2)	P. E. (3) ±	RM (4)	λM (5)	P.E. (6) ±	λo—λm (7)	λu—λm (8)	CURTISS (9)	SCHLESINGER & BAKER (10)	ROWLAND'S STANDARD (11)	REMARKS (12)
55.5296	3958.380	0.0047	55.5294	3958.378	0.0034	−0.015	−0.015		.385	3958.366	G 3.5
55.8924	3963.004	0.0031	55.8924	3963.003	0.0023	+0.002	−0.002	3963.006	.013	3963.013	G 1.8
56.0008	3964.390	0.0038	56.0014	3964.398	0.0028	+0.017	+0.004		.408	3964.429	G 1.8
57.9676	3989.936	0.0042	57.9678	3989.939	0.0031	−0.003	+0.009	3989.885	.921	3989.930	G 7 Br.
58.6388	3998.827	0.0036	58.6389	3998.828	0.0026	−0.007	+0.008	3998.805	.820	3998.804	G 7 Br.
59.4076	4009.131	0.0046	59.4081	(4009.137)	0.0034	+0.038	−0.014	4009.109		4009.133	G 4 Br.
59.6598	4012.537	0.0048	59.6605	(4012.547)	0.0035	−0.033	+0.044		.567	4012.550	F 3
60.5617	4024.833	0.0042	60.5611	4024.824	0.0031	+0.017	−0.030			4024.733	G 5 Br.
60.6963	4026.681	0.0067	60.6915	4026.614	0.0057	+0.028				4026.691	F 1
60.8279	4028.495	0.0034	60.8282	4028.499	0.0025	+0.009	+0.002	4028.469	.512	4028.495	G 4
60.9833	4030.640	0.0039	60.9826	4030.630	0.0033	−0.026				4030.652	F 1
62.0866	4045.997	0.0053	62.0859	4045.987	0.0045	−0.028				4045.975	F 0.5 Fe 3
62.6499	4053.949	0.0043	62.6508	4053.962	0.0032	−0.013	+0.036	4053.985	.982	4053.982	G 2
62.7269	4055.042	0.0056	62.7272	4055.046	0.0048	+0.013				4055.181	F 1
63.1048	4060.420	0.0056	63.1051	4060.424	0.0048	+0.012			.412	4060.422	G 1.5
63.4097	4064.781	0.0046	63.4093	4064.774	0.0039	−0.018					F 2 Bl (2 lines)
64.3707	4078.659	0.0027	64.3704	(4078.654)	0.0020	−0.051	+0.026	4078.635	.618	4078.632	G 4
64.6431	4082.635	0.0045	64.6426	4082.627	0.0039	−0.023		4082.623		4082.609	G 2.5
66.6769	4112.845	0.0074	66.6766	4112.841	0.0063	−0.011		4112.882		4112.874	F 1.5
67.3056	4122.384	0.0063	67.3053	4122.380	0.0054	−0.012				4122.316	P 0.5
67.3859	4123.609	0.0062	67.3862	4123.614	0.0053	+0.014					F 0.8 Bl (2 lines)
67.6553	4127.797	0.0065	67.6553	4127.797	0.0056	±0.000				4127.692	F 0.8
68.2813	4137.380	0.0051	68.2816	4137.385	0.0044	+0.014				4137.437	F 1
69.1585	4151.059	0.0056	69.1585	4151.059	0.0048	−0.001					P 1
69.9690	4163.888	0.0046	69.9682	4163.876	0.0034	−0.025	−0.007	4163.829	.845	4163.829	G 8
70.4784	4172.028	0.0048	70.4786	4172.032	0.0035	−0.022	+0.023	4172.071	.063	4172.077	G 7
71.3592	4186.282	0.0048	71.3590	4186.280	0.0035	−0.007	+0.001	4186.301	.285	4186.301	G 2
73.8409	4227.591	0.0075	73.8404	4227.582	0.0064	−0.024					F 15 Fe (?)
74.4513	4238.003	0.0046	74.4516	4238.008	0.0039	+0.014		4238.031		4238.031	F 1
75.5019	4256.222	0.0080	75.5025	4256.233	0.0069	+0.031				4256.208	F 1
75.9070	4263.336	0.0056	75.9074	4263.343	0.0041	+0.006	+0.010	4263.366	.289	4263.295	G 3.5
76.5514	4274.755	0.0059	76.5525	4274.775	0.0043	+0.005	+0.036	4274.736	.763	4274.746	G 2
76.7524	4278.348	0.0052	76.7518	4278.337	0.0045	−0.032				4278.368	F 1
77.6297	4294.163	0.0067	77.6326	(4294.215)	0.0049	−0.015	+0.048		.266	4294.273	G 5
78.2786	4306.024	0.0076	78.2794	4306.039	0.0056	+0.002	+0.029			4306.081	G 5
78.3898	4308.067	0.0083	78.3880	(4308.035)	0.0061	−0.003	−0.061	4308.031		4308.068	G 4
78.7717	4315.141	0.0076	78.7711	4315.130	0.0056	−0.037	+0.005	4315.066			G 5 Bl (2 lines)
78.9698	4318.803	0.0072	78.9693	4318.795	0.0062	−0.025		4318.797		4318.818	F 2
79.3491	4325.886	0.0065	79.3491	4325.887	0.0056	+0.003					F 2 Bl (2 lines)
79.6056	4330.701	0.0072	79.6057	4330.702	0.0062	+0.004				4330.873	F 1
79.9986	4338.123	0.0099	79.9993	4338.136	0.0073	−0.002	+0.027	4338.117	.082	4338.081	G 10
80.0013	4338.142	0.0065	80.0010	4338.137	0.0048	−0.027	+0.011			4338.081	G 10
80.1800	4341.522	0.0042	80.1799	4341.521	0.0036	−0.003				4341.534	F 1
80.3319	4344.406	0.0078	80.3314	4344.398	0.0067	−0.025				4344.456	F 1
80.6784	4351.011	0.0051	80.6788	4351.018	0.0044	+0.022				4351.001	F 1
81.5489	4367.795	0.0072	81.5496	(4367.808)	0.0053	−0.049	+0.063	4367.823	.876	4367.843	F 3
81.9201	4375.019	0.0050	81.9202	4375.021	0.0043	+0.007				4374.963	F 1
82.5312	4387.050	0.0062	82.5316	4387.058	0.0053	+0.022				4387.025	F 2
83.1753	4399.882	0.0068	83.1756	4399.888	0.0050	+0.002	+0.010	4399.944	.931	4399.944	G 3
83.4069	4404.536	0.0056	83.4064	4404.526	0.0041	−0.005	−0.015			4404.486	F 2
83.7385	4411.238	0.0062	83.7382	4411.234	0.0046	+0.023	−0.025			4411.252	G 1.5
84.0593	4417.766	0.0042	84.0595	(4417.771)	0.0031	−0.037	+0.037	4417.844			G 10 Bl (2lines)
85.3312	4444.049	0.0097	85.3305	4444.033	0.0071	−0.014	−0.022	4444.026		4443.975	G 10
85.5806	4449.274	0.0097	85.5834	4449.334	0.0079		+0.120			4449.326	G 4
85.6602	4450.946	0.0090	85.6579	4450.898	0.0074		−0.095				G 4 Bl (2 lines)

Rm (1)	λm (2)	P. E. (3) ±	RM (4)	λM (5)	P.E. (6) ±	λo—λm (7)	λu—λm (8)	CURTISS (9)	SCHLESINGER & BAKER (10)	ROWLAND'S STANDARD (11)	REMARKS (12)
85.7788	4453.436	0.0069	85.7806	4453.475	0.0056		+0.078	4453.589			G 4 Bl (2 lines)
85.8732	4455.437	0.0071	85.8719	4455.411	0.0058		—0.053		.485	4455.493	G 4
85.9771	4457.632	0.0097	85.9751	4457.591	0.0079		—0.082	4457.563	.596	4457.603	G 5
86.4979	4468.709	0.0046	86.4982	4468.716	0.0034	+0.021	—0.002	4468.692	.676	4468.664	G 9
86.6102	4471.113	0.0082	86.6115	4471.140	0.0070	+0.076		4471.298			G 1 Bl (2 lines)
87.0882	4481.376	0.0097	87.0880	4481.371	0.0071	+0.003	—0.012	4481.391		4481.439	G 3.5
87.4292	4488.787	0.0095	87.4290	(4488.784)	0.0070	+0.052	—0.043				G 6 Bl (2 lines)
87.7747	4496.324	0.0068	87.7746	4496.322	0.0058	—0.005		4496.196	.319	4496.327	G 3
88.0084	4501.453	0.0073	88.0090	(4501.467)	0.0054	+0.044	—0.009	4501.423	.434	4501.449	F 10
88.5283	4512.946	0.0070	88.5272	4512.927	0.0051	—0.031	—0.016	4512.974	.909	4512.906	G 6
88.7677	4518.277	0.0055	88.7677	4518.279	0.0040	+0.026	—0.016	4518.246		4518.202	G 7
88.9770	4522.938	0.0090	88.9771	4522.940	0.0066	+0.031	—0.018	4522.961	.983	4522.981	G 7
89.1760	4527.421	0.0097	89.1767	(4527.442)	0.0071	—0.078	+0.087		.488	4527.485	G 5
89.9470	4544.902	0.0073	89.9474	4544.912	0.0054	—0.012	+0.034	4544.868	.875	4544.864	G 5
90.4144	4555.627	0.0081	90.4138	(4555.613)	0.0059	+0.053	—0.064		.576	4555.671	G 5 close line
90.7738	4563.940	0.0074	90.7741	4563.948	0.0054	+0.037	—0.011	4563.956		4563.947	G 8
91.1275	4572.179	0.0071	91.1276	4572.181	0.0052	+0.019	—0.009			4572.158	F 10
91.8898	4590.134	0.0079	91.8894	4590.124	0.0068	—0.026				4590.139	F 2
93.0282	4617.461	0.0086	93.0280	4617.457	0.0063	+0.001	+0.006	4617.457	.458	4617.440	G 8
93.2674	4623.281	0.0082	93.2673	4623.278	0.0060	+0.019	—0.019	4623.285	.264	4623.268	G 2.5
93.9396	4639.801	0.0040	93.9399	(4639.809)	0.0029	+0.043	—0.015				G 8 Bl (3 lines)
94.1608	4645.285	0.0060	94.1603	4645.274	0.0051	—0.029				4645.350	P 0.8
94.6160	4656.660	0.0108	94.6159	4656.658	0.0079	—0.018	+0.010	4656.612		4656.622	G 5
95.0571	4667.785	0.0090	95.0565	(4667.770)	0.0066	—0.055	+0.011	4667.777	.777	4667.750	F 4
95.6177	4682.078	0.0078	95.6175	4682.074	0.0057	+0.007	—0.011	4682.072	.071	4682.084	G 6
95.9818	4691.450	0.0107	95.9819	4691.453	0.0092	+0.010				4691.504	F 1.5
96.2702	4698.930	0.0065	96.2708	4698.945	0.0056	+0.040				4698.940	F 1.5
97.9324	4742.929	0.0081	97.9326	4742.933	0.0069	+0.012			.942	4742.965	F 1.5
98.5220	4758.917	0.0086	98.5217	4758.909	0.0063	—0.030	+0.005	4758.926			F 6 Bl (3 lines)
100.1920	4805.333	0.0122	100.1914	(4805.316)	0.0089	—0.083	+0.008	4805.469			G 4 Bl (2 lines)
101.4365	4841.055	0.0090	101.4359	4841.037	0.0066	—0.007	—0.031	4841.003	.075	4841.038	G 3
101.9519	4856.142	0.0119	101.9518	4856.139	0.0087	±0.000	—0.006	4856.211	.162	4856.187	F 2
102.4024	4869.475	0.0102	102.4025	4869.477	0.0088	+0.005					P 1.5 Bl (2 lines)
102.9296	4885.255	0.0099	102.9300	(4885.268)	0.0073	+0.053	—0.013	4885.257	.268	4885.249	G 1.5
103.4192	4900.077	0.0093	103.4194	4900.085	0.0054	+0.023				4900.089	G 2
106.0266	4981.933	0.0115	106.0266	4981.931	0.0084	—0.011	+0.005	4981.884		4981.916	G 5
106.3118	4991.194	0.0054	106.3118	4991.193	0.0040	—0.009	+0.004	4991.147		4991.248	G 4
106.5729	4999.728	0.0066	106.5728	4999.726	0.0048	+0.015	—0.014	4999.770		4999.683	F 4
106.8060	5007.393	0.0119	106.8054	(5007.376)	0.0087	—0.077	+0.022	5007.435		5007.391	G 4
107.0217	5014.524	0.0092	107.0217	(5014.524)	0.0068	+0.053	—0.037			5014.411	F 3.5
107.6730	5036.280	0.0119	107.6733	(5036.289)	0.0087	—0.017	+0.033				P 2 Bl (2 lines)

Lines of the greatest brightness in the spark spectrum are referred to in column 12 as having an intensity 10; other lines are given an intensity varying from 9 to 0.2, depending on their estimated brightness. The character of the lines is denoted by the letters G, F, P, Bl, and Br., signifying good, fair, poor, blend, and broad. Provisional weights, ranging from 0 to 4, were assigned to the various lines for convenience, according to their character on the negative.

The mean of the screw readings, R_o and R_u, made on the over and under exposed plates were reduced to the dispersion formerly used. Column 4 contains R_M, which represents the weighted means of the three values designated by R_m, R_o and R_u. The differences between the wave-lengths corresponding to these screw readings, of lines having weights 2, 3, and 4, and the similar values in Rowland's standard were then plotted as ordinates against their wave-lengths as

abscissae and a correction curve was drawn through these residuals. In drawing this curve those lines which showed pronounced changes in position with variation of exposure time were not taken into account. The computed wave-lengths were then corrected from the correction curve and their final values, λ_M, corresponding to their screw readings, R_M, are given in column 5. Lines which change their relative positions are enclosed in parentheses and are to be considered as unreliable. Columns 7 and 8 contain respectively, $\lambda_o - \lambda_m$ and $\lambda_u - \lambda_m$, where λ_o is the wave-length of any line determined from the over exposed plates and λ_u the corresponding wave-lengths determined from under exposures. The quantities in these two columns thus show at a glance the effect of varying exposure on the positions of the several lines. The final probable errors for lines measured on the three sets of plates are found in column 6.

In the first column, Table II, are found the screw readings for each whole turn of the screw, and the corresponding values of λ and $d\lambda/dR$ are given in the next two columns. The last two columns give the values of $dV/d\lambda$, derived by dividing the velocity of light in kilometers per second by the wave-length, and the values of dV/dR, which represent radial velocities resulting from each half turn of the screw. The results tabulated here are for future reference, in connection with work done at this Observatory.

TABLE II.

R	$\frac{d\lambda}{dR}$	λ	$\frac{dv}{d\lambda}$	$\frac{dv}{dR}$
(1)	(2)	(3)	(4)	(5)
37	9.83	3751	79.94	786
38	9.96	3761	79.73	794
39	10.09	3771	79.52	802
40	10.22	3781	79.31	811
41	10.36	3792	79.08	819
42	10.50	3802	78.87	828
43	10.64	3813	78.64	837
44	10.79	3824	78.42	846
45	10.94	3834	78.21	856
46	11.09	3845	77.99	865
47	11.24	3857	77.74	874
48	11.40	3868	77.52	884
49	11.56	3879	77.30	894
50	11.73	3891	77.07	904
51	11.90	3903	76.83	914
52	12.07	3915	76.59	924
53	12.24	3927	76.36	935
54	12.42	3939	76.13	946
55	12.61	3952	75.88	957
56	12.80	3964	75.65	968
57	12.99	3977	75.40	979
58	13.18	3990	75.15	990
59	13.38	4004	74.89	1002
60	13.59	4017	74.65	1014
61	13.80	4031	74.39	1027
62	14.02	4045	74.13	1039
63	14.24	4059	73.88	1052
64	14.46	4073	73.62	1065
65	14.69	4088	73.35	1078
66	14.93	4103	73.08	1091
67	15.17	4118	72.82	1105
68	15.42	4133	72.55	1119
69	15.68	4149	72.27	1133
70	15.94	4164	72.01	1148
71	16.20	4180	71.73	1162
72	16.48	4197	71.45	1177
73	16.76	4213	71.17	1193
74	17.05	4230	70.89	1209
75	17.34	4248	70.59	1224
76	17.65	4265	70.31	1241
77	17.96	4283	70.01	1257
78	18.28	4301	69.72	1274
79	18.61	4319	69.43	1293
80	18.92	4338	69.12	1308
81	19.27	4357	68.82	1326
82	19.63	4377	68.51	1345
83	19.99	4397	68.20	1363
84	20.37	4417	67.89	1383
85	20.76	4437	67.58	1403
86	21.15	4458	67.26	1423
87	21.56	4480	66.93	1443
88	21.99	4501	66.62	1465
89	22.42	4524	66.28	1486
90	22.87	4546	65.96	1509
91	23.33	4569	65.63	1531
92	23.80	4593	65.29	1554
93	24.30	4617	64.95	1578
94	24.80	4641	64.61	1602
95	25.32	4667	64.25	1627
96	25.86	4692	63.91	1653
97	26.41	4718	63.56	1679
98	26.99	4745	63.19	1705
99	27.58	4772	62.84	1733
100	28.19	4800	62.47	1761
101	28.82	4829	62.10	1790
102	29.48	4858	61.72	1820
103	30.15	4888	61.35	1850
104	30.85	4918	60.97	1881
105	31.58	4949	60.59	1913
106	32.33	4981	60.20	1946
107	33.10	5014	59.80	1979
108	33.91	5047	59.41	2015

PARALLEL RESULTS.

Ten plates by Curtiss and eight plates by Schlesinger and Baker,[5] made with the Mellon spectrograph of Allegheny Observatory, were reduced separately so as to conform to the above results. The final wave-lengths of the lines measured on these two sets of plates are given in Table 1, columns 9 and 10. The lines whose computed wave-lengths differ by more than 0.1 Å from Rowland's standard are λ 3947, λ 4330, λ 4344, λ 4455, and λ 4555. The wave-lengths of the two adjacent lines λ 4555 and λ 4552 are respectively 0.22 and 0.11 less than the laboratory wave-lengths. The latter line was not included in the table for reasons stated above. Schlesinger and Baker found the differences for these two lines to be respectively 0.09 and 0.11.

[5] *Publications of the Allegheny Observatory*, 1, No. 2, 9-17.

CONCLUSION.

The conclusion drawn from this investigation is that certain lines in the titanium comparison spectrum change their relative positions with variation of exposure time. This displacement is probably due, excepting in the case of titanium lines which naturally blend under low dispersion, to the presence of air lines, although they appear to be comparatively faint. More self-induction may be introduced into the electrical circuit to reduce the relative brightness of the air lines. There could be no objection to such a change since laboratory investigations under high dispersion indicate that the variation of the wave-lengths caused by this alteration in the condition of the spark circuit is too small to affect the work of this instrument. But in any case it would seem advisable to employ those comparison lines which were found to be unaffected by variation of exposure time.

I wish to express my thanks to Dr. Curtiss, whose kindly interest and criticism have been of great importance throughout this investigation.

August, 1913.

OBSERVATIONS OF DOUBLE STARS DISCOVERED AT LA PLATA

THIRTEENTH CATALOGUE

By W. J. HUSSEY

The search which has yielded the new double stars of this Catalogue is an extension of the survey of the northern sky, which was begun by me at the Lick Observatory early in the spring of 1899, and afterward independently by Professor Aitken. This survey was conducted jointly by us, with a zonal division of the sky, from July, 1899, when we each first learned that the other had begun such work, until 1905, when I returned to the University of Michigan. Professor Aitken has continued the work since that time and with more than 2,700 discoveries to his credit he has now nearly completed the survey of the northern sky. And by reason of my connection with the University of La Plata I have been able to commence the examination of the southern stars.

This systematic search for new double stars, which has now resulted in more than four thousand discoveries, had its inception, so far as I am concerned, in a suggestion respecting the need of such work, made by Professor Keeler, in June, 1898, at the time he assumed his duties as Director of the Lick Observatory, and again later in the same year, when in connection with the work which I was doing on the double stars of the Pulkowa Catalogue, new components to a few of the Otto Struve double stars and occasional new pairs in the vicinity of these were found.

The double stars of the present Catalogue were discovered with the 17-inch refractor of the La Plata Observatory, mostly during the latter part of 1911. No micrometer was then available for measuring position angles and distances with this telescope, but it was expected that one would be fitted to it in a few months and that measurements could then be made of the new pairs which were being found. After my return to La Plata in July, 1912, however, my time was so taken with other duties that I was not able to give much attention to this work and consequently many pairs are still unmeasured. In order not to delay the announcement of these discoveries too long some are included in this list with the rough estimates only of position angle and distance which were made at the time of discovery.

The numbers assigned to the double stars of this Catalogue are in continuation of those given in my earlier catalogues of new double stars, printed in *The Astronomical Journal*, Nos. 480, 485, 494, and in the *Bulletins of the Lick Observatory*, Nos. 12, 21, 27, 57, 65, 74, 77, 81, 117. The number of double stars announced in these twelve catalogues is 1337. While at the Lick Observatory I suspected a faint and comparatively close companion to the principal component of Σ 1448, whose existence has since been verified by Professor Aitken with the large refractor of the Lick Observatory. His measures of it are given in *Lick Observatory Bulletin*, No. 184, with the designation, Hu. 1338. Accordingly the present list begins with Hu. 1339 and continues to Hu. 1550. A number of additional pairs have been found at La Plata, which will be published in a subsequent list.

The right ascensions and declinations given below are for the epoch 1875. They have been taken from the *Cape Photographic Durchmusterung*. The sidereal time of observation and the power used are given in the last two columns.

Hu. 1339. C.P.D. —54° 19

R.A. $0^h\ 2^m\ 43^s$; Decl. —54° 41′.8.

(7.5 . . . 8.5)

1913.787	284°.7	0.″39	$22^h.1$	670

Hu. 1340. C.P.D. —48° 76

R.A. $0^h\ 37^m\ 46^s$; Decl. —48° 34′.1

(8.8 . . . 9.5)

1913.718	211.2	1.57	22.6	670
.819	213.2	1.62	5.0	400
1913.77	212.2	1.60		

Hu. 1341. C.P.D. —45° 112

R.A. $0^h\ 55^m\ 30^s$; Decl. —45° 58′.5

(9.0 . . . 10.5) nf. 2″

Hu. 1342. C.P.D. —57° 251

R.A. $1^h\ 4^m\ 9^s$; Decl. —57° 15′.7
(7.0 . . . 7.5)

1913.819	348.1	0.33	5.9	670

Hu. 1343. C.P.D. —46° 121

R.A. $1^h\ 6^m\ 1^s$; Decl. —46° 7′.8
(8.5 . . . 8.8)

1913.718	252.8	3.60	23.0	300

Hu. 1344. C.P.D. —47° 174

R.A. $1^h\ 25^m\ 51^s$; Decl. —47° 2′.2
(8.8 . . . 9.2)

1913.718	103.0	1.55	23.3	300

Hu. 1345. C.P.D. —57° 330

R.A. $1^h\ 29^m\ 30^s$; Decl. —57° 38′.5
(6.5 . . . 12.0)

1913.787	201.0	5.42	23.3	300

Hu. 1346. C.P.D. —45° 189

R.A. $1^h\ 35^m\ 10^s$; Decl. —45° 40′.2
(8.5 . . . 10.5) nf. 5″

Hu. 1347. C.P.D. —48° 245

R.A. $2^h\ 1^m\ 53^s$; Decl. —48° 24′.0
(9.0 . . . 9.5)

1913.718	320.0	0.83	23.7	300

Hu. 1348. C.P.D. —57° 448

R.A. $2^h\ 23^m\ 33^s$; Decl. —57° 18′.0
(10 . . . 10) 120° 0″.5

Hu. 1349. C.P.D. —48° 286

R.A. $2^h\ 27^m\ 11^s$; Decl. —48° 54′.3
(9.0 . . . 10.5)

1913.718	332.8	8.85	0.1	300

Hu. 1350. C.P.D. —54° 464

R.A. $2^h\ 35^m\ 43^s$; Decl. —54° 57′.2
(8.8 . . . 10.0) 210° 0″.5

Hu. 1351. C.P.D. —48° 311

R.A. $2^h\ 46^m\ 7^s$; Decl. —48° 37′.3
(9.0 . . . 9.0)

1913.718	108.6	1.42	0.3	300

Hu. 1352. C.P.D. —56° 478

R.A. $2^h\ 53^m\ 34^s$; Decl. —56° 43′.1
(9.5 . . . 10.0) 185° 1″.5

Hu. 1353. C.P.D. —56° 506

R.A. $3^h\ 10^m\ 24^s$; Decl. —56° 31′.8
(9.5 . . . 11.5)

1913.787	190.6	2.59	0.5	300

Hu. 1354. C.P.D. —43° 351

R.A. $3^h\ 12^m\ 54^s$; Decl. —43° 52′.0
(8.4 . . . 13.0)

1912.853	161.4	2.08	...	300
.856	160.7	2.21	1.3	300
.859	161.8	2.20	0.4	300
1912.86	161.3	2.16		

Hu. 1355. C.P.D. —45° 328

R.A. $3^h\ 15^m\ 14^s$; Decl. —45° 33′.7
(8.4 . . . 12.0)

1912.853	314.4	1.45	0.8	300
.916	314.3	1.57	1.2	300
1912.88	314.4	1.51		

A neighboring pair was measured as follows:

1912.859	287.6	5.06	0.7	300

Magnitudes: 9.5 . . . 9.8

Hu. 1356. C.P.D. —45° 339

R.A. $3^h\ 20^m\ 39^s$; Decl. —45° 31′.0
(9.5 . . . 10.5)

1912.853	181.4	1.40	1.0	300
.859	182.5	1.44	0.9	300
.916	183.5	1.54	1.2	300
1912.87	182.5	1.46		

Hu. 1357. C.P.D. —55° 527

R.A. $3^h\ 23^m\ 32^s$; Decl. —55° 54′.2
(8.0 . . . 8.2)

1913.787	20.8	1.35	0.9	300

Hu. 1358. C.P.D. —49° 436

R.A. $3^h\ 34^m\ 16^s$; Decl. —49° 13′.4
(8.5 . . . 11.0) 280° 4″

Hu. 1359. C.P.D. —47° 382

R.A. $3^h\ 43^m\ 49^s$; Decl. —47° 23′.9
(9.3 . . . 9.3) 130° 0″.8

Hu. 1360. C.P.D. —42° 378

R.A. $3^h\ 52^m\ 15^s$; Decl. —42° 59′.4
(9.2 . . . 9.8)

1912.853	39.1	1.59	1.2	300
.856	36.1	1.62	1.8	300
.859	36.6	1.83	1.1	300
1912.86	37.3	1.68		

Hu. 1361. C.P.D. —48° 418

R.A. 3^h 52^m 21^s; Decl. —48° 8′.0
(7.7 . . . 11.2)

1912.894	83.0	4.33	1.3	300
.897	82.5	4.11	1.1	300
1912.90	82.8	4.22		

Hu. 1362. C.P.D. —48° 437

R.A. 4^h 00^m 02^s; Decl. —48° 5′.2
(9.5 . . . 10.5)

1912.894	65.0	2.11	1.4	300
.897	62.6	1.96	1.2	300
1912.90	63.8	2.04		

Hu. 1363. C.P.D. —22° 458

R.A. 4^h 01^m 33^s; Decl. —22° 19′.7
(7.5 . . . 7.5) ... 0″.3

Hu. 1364. C.P.D. —54° 626

R.A. 4^h 3^m 53^s; Decl. —54° 19′.7
(9.2 . . . 11.5)

1912.877	83.9	5.00	0.9	300
1913.787	84.7	5.17	1.3	300
1913.33	84.3	5.08		

Hu. 1365. C.P.D. —44° 455

R.A. 4^h 12^m 48^s; Decl. —44° 36′.0
(9.0 . . . 9.5)

1912.853	340.6	1.93	1.4	300
.856	341.0	1.94	2.2	300
.859	343.0	1.96	1.2	300
1912.86	341.5	1.94		

Hu. 1366. C.P.D. —30° 573

R.A. 4^h 12^m 59^s; Decl. —30° 10′.5
(9.3 . . . 11.0) 260° 2″

Hu. 1367. C.P.D. —48° 488

R.A. 4^h 19^m 8^s; Decl. —48° 11′.5
(9.3 . . . 9.3) 260° 0″.8

Hu. 1368. C.P.D. —54° 658

R.A. 4^h 20^m 45^s; Decl. —54° 8′.4
(9.2 . . . 9.5)

1912.877	56.6	2.26	1.3	300
1913.787	56.1	2.28	1.4	300
1913.33	56.4	2.27		

Hu. 1369. C.P.D. —29° 572

R.A. 4^h 20^m 49^s; Decl. —29° 2′.3
(9.0 . . . 9.5) 330° 0″.5

Hu. 1370. C.P.D. —56° 679

R.A. 4^h 24^m 54^s; Decl. —56° 11′.0
(8.8 . . . 9.5)

1912.877	139.4	6.76	1.6	300
.951	138.7	6.54	2.7	300
1913.787	139.6	6.59	1.6	300
1913.20	139.2	6.63		

Hu. 1371. C.P.D. —31° 560

R.A. 4^h 28^m 13^s; Decl. —31° 23′.3
(8.8 . . . 8.8) ... 0″.7

Hu. 1372. C.P.D. —42° 492

R.A. 4^h 28^m 31^s; Decl. —42° 46′.3
(9.2 . . . 9.8)

1912.853	280.1	3.90	1.8	300
.856	281.4	3.97	2.3	300
.859	280.2	3.73	....	300
1912.86	280.6	3.87		

Hu. 1373. C.P.D. —55° 666

R.A. 4^h 32^m 1^s; Decl. —55° 17′.6
(9.2 . . . 9.8)

1912.877	80.1	1.15	1.8	300

Hu. 1374. C.P.D. —24° 691

R.A. 4^h 37^m 58^s; Decl. —24° 44′.3
(9.0 . . . 10.0) 90° 0″.7

Hu. 1375. C.P.D. —55° 685

R.A. 4^h 39^m 19^s; Decl. —55° 02′.2
(8.0 . . . 12.0)

1912.877	179.5	4.06	1.9	300
.932	183.4	3.46	2.9	300
.938	182.5	3.90	2.0	300
.943	180.2	3.62	2.9	300
1912.92	181.4	3.76		

Hu. 1376. C.P.D. —44° 527

R.A. 4^h 42^m 06^s; Decl. —44° 30′.7
(8.5 . . . 10.5)

1912.853	314.8	5.37	2.2	300
.856	315.8	5.42	2.6	300
.859	315.5	5.51	....	300
1912.86	315.4	5.43		

Hu. 1377. C.P.D. —44° 536

R.A. $4^h\ 43^m\ 55^s$; Decl. —44° 35′.9
(10.0 . . . 10.5)

1912.853	325.4	6.02	2.4	300
.856	325.8	5.90	2.7	300
.859	325.3	6.07	....	300
1912.86	325.5	6.00		

Hu. 1378. C.P.D. —42° 534

R.A. $4^h\ 43^m\ 58^s$; Decl. —42° 06′.6
(9.0 . . . 10.0)

1912.859	273.0	0.98	1.6	300
.916	272.9	1.33	1.8	300
.919	272.9	1.25	2.2	300
1912.90	272.9	1.19		

Hu. 1379. C.P.D. —57° 707

R.A. $4^h\ 48^m\ 00^s$; Decl. —57° 56′.8
(8.5 . . . 9.0) 300° 0″.7

Hu. 1380. C.P.D. —33° 621

R.A. $4^h\ 48^m\ 06^s$; Decl. —33° 18′.5
(8.5 . . . 10.5) 240° 2″

Hu. 1381. C.P.D. —32° 635

R.A. $4^h\ 49^m\ 19^s$; Decl. —32° 12′.4
(8.5 . . . 11.0) 300° 2″

Hu. 1382. C.P.D. —31° 664

R.A. $4^h\ 53^m\ 54^s$; Decl. —31° 50′.0
(8.5 . . . 10.0) 20° 1″

Hu. 1383. C.P.D. —55° 722

R.A. $4^h\ 55^m\ 20^s$; Decl. —55° 42′.1
(8.5 . . . 11.0)

1912.877	2.9	3.31	2.4	300
.932	6.5	3.08	2.5	300
.935	6.6	3.23	2.6	300
1912.91	5.3	3.21		

Hu. 1384. C.P.D. —43° 530

R.A. $4^h\ 56^m\ 00^s$; Decl. —43° 30′.4
(9.2 . . . 11.5)

1912.853	339.7	4.78	2.5	300
.856	338.8	4.73	2.8	300
.859	341.5	5.01	....	300
1912.86	340.0	4.84		

Hu. 1385. C.P.D. —23° 676

R.A. $4^h\ 57^m\ 03^s$; Decl. —23° 54′.8
(9.5 . . . 9.5) .... 1″.5

Hu. 1386. C.P.D. —45° 570

R.A. $5^h\ 04^m\ 04^s$; Decl. —45° 55′.8
(8.5 . . . 12.0)

1913.859	53.1	7.96	2.1	300
.916	52.9	7.84	2.2	300
1913.87	53.0	7.90		

Hu. 1387. C.P.D. —42° 608

R.A. $5^h\ 4^m\ 22^s$; Decl. —42° 32′.5
(9.0 . . . 10.0)

1912.916	238.4	0.91	2.0	300

Hu. 1388. C.P.D. —49° 658

R.A. $5^h\ 6^m\ 33^s$; Decl. —49° 30′.4
(9.0 . . . 9.0)

1912.845	98.5	0.93	....	300

Hu. 1389. C.P.D. —31° 740

R.A. $5^h\ 11^m\ 28^s$; Decl. —31° 05′.5
(8.0 . . . 8.5) 130° 1″

Hu. 1390. C.P.D. —55° 772

R.A. $5^h\ 13^m\ 8^s$; Decl. —55° 21′.9
(9.0 . . . 9.5)

1912.877	137.0	1.67	2.8	300
.932	136.6	1.99	3.5	300
.935	136.1	1.71	3.0	300
1912.91	136.6	1.77		

Hu. 1391. C.P.D. —55° 787

R.A. $5^h\ 15^m\ 42^s$; Decl. —55° 50′.3
(8.8 . . . 10.2)

1912.877	201.2	2.30	2.9	300
.932	198.8	2.18	3.3	300
.935	199.7	2.30	3.2	300
1912.91	199.9	2.26		

Hu. 1392. C.P.D. —44° 595

R.A. $5^h\ 21^m\ 21^s$; Decl. —44° 35′.9
(8.8 . . . 11.5)

1912.856	21.8	3.80	3.1	300

Hu. 1393. C.P.D. —33° 852

R.A. $5^h\ 30^m\ 52^s$; Decl. —33° 21′.1
(7.0 . . . 7.0) ... 0″.3

Hu. 1394. C.P.D. —42° 709

R.A. $5^h\ 33^m\ 22^s$; Decl. —42° 47′.5
(8.8 . . . 11.0)

1912.856	120.4	4.07	3.4	300
.859	119.6	3.94	....	300
1912.86	120.0	4.00		

Hu. 1395. C.P.D. —56° 949

R.A. $5^h\ 48^m\ 01^s$; Decl. —56° 50′.1
(8.5 . . . 9.0)

1912.877	55.6	1.05	3.7	300
.932	54.0	0.86	4.0	300
.935	57.1	1.06	3.6	300
1912.91	55.6	0.99		

Hu. 1396. C.P.D. —30° 1071

R.A. $5^h\ 49^m\ 00^s$; Decl. —30° 42′.1
(8.6 . . . 10.0) 140° 2″

Hu. 1397. C.P.D. —44° 744

R.A. $5^h\ 50^m\ 35^s$; Decl. —44° 41′.4
(9.0 . . . 10.0)

1912.856	90.8	3.20	3.7	300
.859	91.8	3.33	...	300
.916	88.7	3.38	2.6	300
1912.89	90.4	3.30		

Hu. 1398. C.P.D. —41° 853

R.A. $5^h\ 53^m\ 11^s$; Decl. —41° 46′.2
(8.0 . . . 8.5)

1912.856	212.5	1.91	3.8	300
.859	215.5	1.69	...	300
.916	214.0	1.86	2.7	300
1912.88	214.0	1.82		

Hu. 1399. C.P.D. —31° 976

R.A. $5^h\ 55^m\ 40^s$; Decl. —31° 03′.0
(9.0 . . . 9.5) 340° 0″.8
Companion of Cordoba General Catalogue pair.

Hu. 1400. C.P.D. —54° 936

R.A. $5^h\ 57^m\ 16^s$; Decl. —54° 37′.3
(8.5 . . . 9.8)

1912.877	13.6	2.45	3.4	300
.924	13.4	2.08	2.3	300
.932	14.6	2.31	4.3	300
1912.91	13.9	2.28		

Hu. 1401. C.P.D. —56° 982

R.A. $5^h\ 57^m\ 20^s$; Decl. —56° 38′.2
(8.8 . . . 11.5)

1912.877	212.7	4.97	3.5	300
.932	213.0	5.07	4.1	300
.935	213.7	5.09	3.7	300
1912.91	213.1	5.04		

Hu. 1402. C.P.D. —55° 921

R.A. $5^h\ 57^m\ 36^s$; Decl. —55° 13′.4
(8.7 . . . 9.8)

1912.877	294.4	1.23	3.3	300
.932	294.8	1.22	4.3	300
.935	295.6	1.27	3.9	300
1912.91	294.9	1.24		

Hu. 1403. C.P.D. —48° 767

R.A. $5^h\ 58^m\ 42^s$; Decl. —48° 56′.1
(9.0 . . . 9.3)

1912.845	91.8	1.18	2.8	300
1913.241	90.8	1.37	9.1	300
.244	88.8	1.28	8.7	300
1913.11	90.5	1.28		

Hu. 1404. C.P.D. —54° 950

R.A. $6^h\ 00^m\ 5^s$; Decl. —54° 21′.8
(9.0 . . . 10.0)

1912.877	184.6	0.95	3.8	300
.932	188.1	0.78	4.5	300
.935	185.0	1.15	4.1	300
.938	187.1	1.01	3.3	300
1912.92	186.2	0.97		

Hu. 1405. C.P.D. —43° 783

R.A. $6^h\ 10^m\ 17^s$; Decl. —43° 06′.1
(9.5 . . . 10.0)

1912.916	211.8	2.43	3.2	300
1913.244	208.0	2.45	10.0	300
1913.08	209.9	2.44		

Hu. 1406. C.P.D. —56° 1043

R.A. $6^h\ 13^m\ 10^s$; Decl. 56° 6′.8
(9.0 . . . 11.5)

1912.877	189.8	2.37	4.2	300
.935	187.7	2.48	4.2	300
.938	187.5	2.37	3.5	300
1912.92	188.3	2.41		

Hu. 1407. C.P.D. —57° 973

R.A. $6^h\ 13^m\ 21^s$; Decl. —57° 00′.8
(8.5 . . . 11.2)

1912.877	77.1	2.69	4.1	300
.935	79.3	2.45	4.4	300
.938	76.7	2.89	3.7	300
1912.92	77.7	2.68		

Hu. 1408. C.P.D. —42° 890

R.A. 6h 15m 29s; Decl. —42° 25'.9
(8.8 . . . 9.0)

1912.900	6.4	0.54	3.8	300
.916	8.4	0.58	3.3	300
1913.244	13.4	0.42	10.2	670
1913.02	9.4	0.51		

Hu. 1409. C.P.D. —56° 1059

R.A. 6h 17m 11s; Decl. —56° 30'.8
(9.0 . . . 12.0)

1912.877	201.1	1.89	4.5	300
.938	201.9	2.17	3.8	300
1912.91	201.5	2.02		

Hu. 1410. C.P.D. —46° 817

R.A. 6h 20m 50s; Decl. —46° 52'.2
(8.6 . . . 12.5)

1912.845	315.8	6.59	3.4	300
.919	319.1	6.23	3.6	300
1913.241	316.2	6.64	9.4	300
1913.00	317.0	6.49		

Hu. 1411. C.P.D. —55° 998

R.A. 6h 23m 18s; Decl. —55° 5'.3
(9.2 . . . 9.2) 130° 0".5

Hu. 1412. C.P.D. —44° 916

R.A. 6h 24m 32s; Decl. —44° 42'.8
(8.8 . . . 12.5)

1912.856	263.4	3.88	4.0	300
.916	263.0	3.72	3.6	300
1912.89	263.2	3.80		

Hu. 1413. C.P.D. —44° 917

R.A. 6h 24m 54s; Decl. —44° 15'.9
(8.8 . . . 12.0)

1912.856	29.8	1.39	4.2	300
.900	29.5	1.47	4.0	300
.916	29.1	1.44	3.5	300
1913.244	29.5	1.42	10.9	670
1912.98	29.5	1.43		

Hu. 1414. C.P.D. —42° 981

R.A. 6h 32m 24s; Decl. —42° 31'.6
(9.2 . . . 9.2)

1912.916	97.0	0.54	3.9	300
1913.244	96.1	0.44	10.5	670
1913.08	96.6	0.49		

Hu. 1415. C.P.D. —44° 1018

R.A. 6h 33m 5s; Decl. —44° 57'.3
(7.6 . . . 12.0)

1912.900	28.9	2.01	4.3	300
.916	32.6	1.82	3.8	300
1913.244	26.7	1.89	10.6	670
1913.02	29.4	1.91		

Principal component of h 3882.

h 3882

1912.900	331.0	7.92	4.4	300

Hu. 1416. C.P.D. —42° 1051

R.A. 6h 41m 40s; Decl. —42° 24'.1
(8.6 . . . 10.0)

1912.900	82.6	1.27	4.6	300
.916	85.6	1.18	4.1	300
1913.244	88.0	1.05	11.1	300
1913.02	85.4	1.17		

Hu. 1417. C.P.D. 1103.

R.A. 6h 51m 00s; Decl. —45° 44'.1
(8.4 . . . 9.2)

1912.856	142.0	1.32	4.8	300
.900	145.9	1.59	4.8	300
.916	143.6	1.28	4.2	300
1912.87	143.8	1.40		

Hu. 1418. C.P.D. —45° 1175

R.A. 6h 59m 13s; Decl. —45° 34'.0
(8.0 . . . 10.5)

1912.856	338.6	2.55	4.9	300
.900	338.4	2.51	4.9	300
.916	341.8	2.65	4.4	300
1912.89	339.6	2.57		

Hu. 1419. C.P.D. —44° 1254

R.A. 7h 00m 12s; Decl. —44° 28'.5
(8.5 . . . 13.5)

1912.916	304.8	3.41	4.6	300
1913.244	308.8	2.94	11.3	300
1913.08	306.8	3.18		

Hu. 1420. C.P.D. —43° 1209

R.A. 7h 02m 59s; Decl. —43° 57'.1
(9.5 . . . 10.0) 190° 1"

Hu. 1421. C.P.D. $-55°$ 1162

R.A. 7^h 05^m 41^s; Decl. $-55°$ 12′.1
(9.5 . . . 9.8)

1912.938	31.3	5.88	4.5	300
.951	29.8	5.88	4.1	300
1912.94	30.6	5.88		

Hu. 1422. C.P.D. $-42°$ 1364

R.A. 7^h 20^m 19^s; Decl. $-42°$ 27′.6
(9.2 . . . 9.8)

1912.900	245.0	1.86	5.4	300

Hu. 1423. C.P.D. $-43°$ 1445

R.A. 7^h 21^m 7^s; Decl. $-43°$ 8′.4
(8.0 . . . 11.5)

1912.900	298.8	5.88	5.3	300
.916	299.9	6.05	5.3	300
1912.91	299.4	5.97		

Hu. 1424. C.P.D. $-48°$ 1188

R.A. 7^h 25^m 34^s; Decl. $-48°$ 11′.7
(9.0 . . . 9.5)

1912.897	18.4	1.23	4.8	300
.919	18.4	1.33	5.4	300
1913.241	17.4	1.49	9.9	670
1913.02	18.1	1.35		

Hu. 1425. C.P.D. $-55°$ 1245

R.A. 7^h 25^m 41^s; Decl. $-55°$ 23′.1
(9.0 . . . 9.5)

1912.877	152.3	5.17	4.9	300
.935	151.5	5.19	4.9	300
1912.91	151.9	5.18		

Hu. 1426. C.P.D. $-42°$ 1577

R.A. 7^h 40^m 11^s; Decl. $-42°$ 43′.1
(9.5 . . . 10.5) 210° 1″.5

Hu. 1427. C.P.D. $-44°$ 1851

R.A. 7^h 41^m 02^s; Decl. $-44°$ 47′.8
(9.2 . . . 9.5) 255° 4″

Hu. 1428. C.P.D. $-46°$ 1757

R.A. 7^h 43^m 01^s; Decl. $-46°$ 29′.6
(7.5 . . . 8.8)

1913.241	354.2	0.35	10.2	670
.244	353.7	0.46	9.3	670
1913.24	354.0	0.40		

Hu. 1429. C.P.D. $-43°$ 1784

R.A. 7^h 43^m 08^s; Decl. $-43°$ 05′.2
(8.0 . . . 8.5) 310° 0″.5

Hu. 1430. C.P.D. $-43°$ 1936

R.A. 7^h 51^m 34^s; Decl. $-43°$ 26′.9
(8.3 . . . 12.0) 142° 5″

Hu. 1431. C.P.D. $-45°$ 1897

R.A. 7^h 52^m 56^s; Decl. $-45°$ 42′.8
(9.0 . . . 9.0) . . . 0″.3

Hu. 1432. C.P.D. $-46°$ 1983

R. A. 7^h 55^m 59^s; Decl. $-46°$ 57′.7
(8.0 . . . 8.0)

1913.244	150.3	0.47	9.5	670

Principal Component of h 4032.

Hu. 1433. C.P.D. $-47°$ 1818

R.A. 8^h 00^m 33^s; Decl. $-47°$ 26′.0
(9.0 . . . 10.0)

1913.244	44.1	2.45	9.6	300

Hu. 1434. C.P.D. $-57°$ 1393

R.A. 8^h 02^m 19^s; Decl. $-57°$ 25′.3
(8.2 . . . 13.0) 315° 5″

Hu. 1435. C.P.D. $-54°$ 1574

R.A. 8^h 14^m 9^s; Decl. $-54°$ 44′.0
(9.0 . . . 11.0)

1913.028	160.9	3.04	4.9	300
.151	160.0	3.29	6.7	300
1913.09	160.5	3.17		

Hu. 1436. C.P.D. $-57°$ 1463

R.A. 8^h 14^m 12^s; Decl. $-57°$ 14′.3
(9.0 . . . 11.0) 120° 5″

Hu. 1437. C.P.D. $-54°$ 1611

R.A. 8^h 19^m 13^s; Decl. $-54°$ 49′.3
(9.0 . . . 10.0)

1913.028	76.5	2.50	5.2	300
.151	74.6	2.50	6.8	300
1913.09	75.5	2.50		

Hu. 1438. C.P.D. $-55°$ 1544

R.A. 8^h 22^m 15^s; Decl. $-55°$ 20′.4
(7.4 . . . 12.0) 200° 6″

Hu. 1439. C.P.D. — 42° 2591

R.A. 8^h 26^m 1^s; Decl. — 42° 45′.3
(8.6 . . . 11.0)

1913.028	121.9	3.09	6.0	300
.034	120.5	3.38	5.4	300
.088	122.3	3.19	5.3	300
1913.05	121.6	3.22		

Hu. 1440. C.P.D. — 43° 2770

R.A. 8^h 30^m 55^s; Decl. — 44° 47′.8
(8.5 . . . 10.0)

1913.017	181.1	1.25	6.7	300
.028	182.1	1.39	6.1	300
.034	180.1	1.18	5.8	300
1913.03	181.1	1.27		

Hu. 1441. C.P.D. — 44° 2817

R.A. 8^h 32^m 46^s; Decl. — 44° 51′.2
(8.8 . . . 10.0)

1913.034	33.5	1.18	6.0	300
.088	31.5	1.42	5.5	300
1913.06	32.5	1.30		

Hu. 1442. C.P.D. — 43° 2874

R.A. 8^h 37^m 16^s; Decl. — 43° 48′.4
(9.0 . . . 9.5)

1913.017	161.4	1.23	6.8	300
.028	164.1	1.39	6.2	300
.034	162.7	1.40	6.3	300
1913.03	162.7	1.34		

Hu. 1443. C.P.D. — 55° 1674

R.A. 8^h 37^m 34^s; Decl. — 55° 43′.3
(8.0 . . . 8.5)

1913.107	262.2	0.60	6.2	300
.151	258.5	0.66	7.0	300
1913.13	260.4	0.63		

Hu. 1444. C.P.D. — 55° 1699

R.A. 8^h 40^m 00^s; Decl. — 55° 54′.7
(9.0 . . . 10.5)

1913.107	34.8	4.41	6.3	300
.151	33.5	4.33	7.1	300
1913.13	34.2	4.37		

Hu. 1445. C.P.D. — 46° 2966

R.A. 8^h 42^m 2^s; Decl. — 46° 56′.3
(8.5 . . . 10.0) 190° 1″.2

Hu. 1446. C.P.D. — 46° 2996

R.A. 8^h 42^m 52^s; Decl. — 46° 40′.7
(9.0 . . . 9.0) 30° 3″

Hu. 1447. C.P.D. — 44° 3143

R.A. 8^h 45^m 57^s; Decl. — 44° 15′.3
(8.4 . . . 12.2)

1913.020	220.8	3.36	5.7	300
.088	219.8	3.48	6.0	300
1913.05	220.3	3.42		

Hu. 1448. C.P.D. — 55° 1788

R.A. 8^h 46^m 09^s; Decl. — 55° 41′.6
(8.4 . . . 11.0)

1913.107	323.2	2.43	5.8.	300
.151	326.1	2.72	7.4	300
.157	324.8	2.48	6.5	300
1913.14	324.7	2.54		

Hu. 1449. C.P.D. — 48° 1966

R.A. 8^h 46^m 16^s; Decl. — 48° 06′.9
(8.8 . . . 10.0) 80° 0″.8

Hu. 1450. C.P.D. — 48° 2072

R.A. 8^h 52^m 04^s; Decl. — 48° 40′.6
(9.0 . . . 10.0) 160° 1″

Hu. 1451. C.P.D. — 47° 2945

R.A. 8^h 52^m 30^s; Decl. — 47° 22′.8
(8.8 . . . 9.2) 320° 0″.8

Hu. 1452. C.P.D. — 43° 3186

R.A. 8^h 53^m 13^s; Decl. — 43° 03′.8
(8.8 . . . 9.2)

1913.020	144.5	1.28	6.4	300
.036	143.1	1.27	6.8	300
.088	143.9	1.33	6.3	300
1913.05	143.8	1.29		

Hu. 1453. C.P.D. — 43° 3257

R.A. 8^h 56^m 59^s; Decl. — 43° 45′.6
(8.5 . . . 10.5)

1913.020	174.2	4.06	6.4	300
.036	174.4	4.27	6.9	300
.088	175.3	4.00	6.5	300
1913.05	174.6	4.11		

Hu. 1454. C.P.D. — 47° 3073

R.A. 9^h 02^m 05^s; Decl. — 47° 40′.8
(8.5 . . . 10.5) 320° 1″.2

Hu. 1455. C.P.D. —47° 3109

R.A. 9^h 05^m 02^s; Decl. —47° 13′.5
(8.5 . . . 10.5) 110° 1″

Hu. 1456. C.P.D. —42° 3467

R.A. 9^h 08^m 12^s; Decl. —42° 58′.5
(8.5 . . . 12.0)

1912.916	159.8	5.36	6.8	300
1913.020	156.3	5.29	7.2	300
.195	159.8	....	7.4	300
1913.04	158.6	5.33		

Hu. 1457. C.P.D. —54° 2113

R.A. 9^h 10^m 38^s; Decl. —54° 28′.4
(8.8 . . . 9.5)

1913.110	265.5	1.12	6.5	300
.151	263.8	1.27	8.0	300
.157	266.1	1.33	6.7	300
1913.14	265.1	1.24		

Hu. 1458. C.P.D. —51° 2051

R.A. 9^h 11^m 17^s; Decl. —51° 38′.2
(9.8 . . . 11.0) ... 1″.5

Hu. 1459. C.P.D. —49° 2412

R.A. 9^h 17^m 21^s; Decl. —49° 08′.0
(8.5 . . . 12.0) 80° 5″

Hu. 1460. C.P.D. —49° 2452

R.A. 9^h 20^m 42^s; Decl. —49° 32′.9
(9.5 . . . 11.0) 130° 1″.5

Hu. 1461. C.P.D. —54° 2319

R.A. 9^h 24^m 00^s; Decl. —54° 33′.8
(9.5 . . . 9.5) ... 1″

Hu. 1462. C.P.D. —48° 2548

R.A. 9^h 30^m 52^s; Decl. —48° 26′.7
(8.5 . . . 10.0) 320° 2″

Hu. 1463. C.P.D. —47° 3415

R.A. 9^h 31^m 00^s; Decl. —47° 26′.1
(10 . . . 11.0) 300° 2″

Hu. 1464. C.P.D. —47° 3423

R.A. 9^h 31^m 19^s; Decl. —47° 28′.1
(9.5 . . . 9.5) 250°, 5″

Hu. 1465. C.P.D. —49° 2622

R.A. 9^h 33^m 01^s; Decl. —49° 26′.1
(7.5 . . . 13.0) 200° 4″

Hu. 1466. C.P.D. —54° 2519

R.A. 9^h 33^m 52^s; Decl. —54° 8′.8
(9.0 . . . 11.5)

1913.122	215.6	3.84	6.9	300
.144	220.7	3.68	7.9	300
.151	216.7	3.56	8.4	300
1913.14	217.7	3.69		

Hu. 1467. C.P.D. —49° 2640

R.A. 9^h 34^m 22^s; Decl. —49° 56′.7
(7.8 . . . 12.0) 300° 6″

Hu. 1468. C.P.D. —57° 2273

R.A. 9^h 39^m 58^s; Decl. —57° 03′.9
(8.5 . . . 11.5)

1913.297	201.1	4.07	13.3	300

Hu. 1469. C.P.D. —57° 2277

R.A. 9^h 40^m 12^s; Decl. —57° 21′.3
(8.5 . . . 11.0)

1913.184	259.1	5.39	7.4	670
.297	257.1	5.59	13.6	300
1913.24	258.1	5.49		

Hu. 1470. C.P.D. —49° 2840

R.A. 9^h 45^m 32^s; Decl. —49° 02′.2
(7.8 . . . 11.0) 20° 6″

Hu. 1471. C.P.D. —57° 2379

R.A. 9^h 47^m 00^s; Decl. —57° 32′.1
(9.0 . . . 10.8)

1913.184	165.9	2.15	7.5	670
.297	169.6	2.37	13.8	300
1913.24	167.8	2.26		

Hu. 1472. C.P.D. —49° 2958

R.A. 9^h 52^m 30^s; Decl. —49° 16′.5
(7.7 . . . 12.5) 360° 1″.5

Hu. 1473. C.P.D. —45° 4343

R.A. 9^h 58^m 41^s; Decl. —45° 39′.3
(8.8 . . . 10.0)

1913.036	328.2	1.03	7.4	300

Hu. 1474. C.P.D. —54° 3101

R.A. 10^h 00^m 59^s; Decl. —54° 04′.8
(9.2 . . . 9.8)

1913.110	179.5	0.86	7.4	300
.151	176.6	0.91	8.6	300
.297	178.5	0.73	14.1	300
1913.19	178.2	0.83		

Hu. 1475. C.P.D. —44° 4788

R.A. 10h 19m 42s; Decl. —44° 26'.1
(8.8 . . . 9.2)

1913.020	261.1	2.49	8.1	300
.034	260.5	2.28	7.8	300
.036	260.7	2.42	8.3	300
.195	260.8	2.16	8.5	300
1913.07	260.8	2.34		

Hu. 1476. C.P.D. —57° 3793

R.A. 10h 42m 03s; Decl. —57° 17'.9
(8.8 . . . . 11.0)

1913.157	109.9	4.68	8.5	300
.184	111.9	4.49	8.2	670
.187	110.3	4.61	7.9	270
1913.17	110.7	4.59		

Hu. 1477. C.P.D. —55° 3928

R.A. 10h 46m 58s; Decl. —55° 29'.7
(9.2 . . . 9.5)

1913.184	237.1	6.02	8.4	300
.187	236.6	5.83	8.2	300
.297	236.8	6.15	14.5	300
1913.22	236.8	6.00		

Hu. 1478. C.P.D. —57° 9643

R.A. 10h 49m 10s; Decl. —57° 46'.5
(9.2 . . . 10.0)

1913.187	330.6	6.08	8.8	240

Hu. 1479. C.P.D. —56° 3987

R.A. 10h 49m 16s; Decl. —56° 26'.9
(9.5 . . . 9.5)

1913.107	109.5	1.12	8.0	300
.110	105.3	1.30	8.3	300
.187	105.9	1.20	8.6	300
.297	106.0	1.03	14.8	300
1913.18	106.7	1.17		

Hu. 1480. C.P.D. —49° 3921

R.A. 10h 57m 10s; Decl. —49° 45'.4
(8.8 . . . 11.5) 290° 4"

Hu. 1481. C.P.D. —55° 4171

R.A. 11h 4m 03s; Decl. —55° 28'.8
(9.0 . . . 9.5) 300° 0".8

Hu. 1482. C.P.D. —55° 4293

R.A. 11h 14m 34s; Decl. —55° 44'.2
(9.0 . . . 9.2)

1913.107	354.7	3.53	9.3	300
.113	354.0	3.70	8.5	300
1913.11	354.4	3.62		

Hu. 1483. C.P.D. —56° 4430

R.A. 11h 16m 02s; Decl. —56° 42'.9
(9.0 . . . 12.0)

1913.113	51.9	1.74	8.7	300

Hu. 1484. C.P.D. —22° 5036

R.A. 11h 30m 00s; Decl. —22° 9'.5
(9.0 . . . 11.0)

1913.277	330.2	1.84	9.7	300

Hu. 1485. C.P.D. —57° 4979

R.A. 11h 40m 22s; Decl. —57° 20'.2
(8.0 . . . 11.8 . . . 11.5)

AB

1913.157	317.1	2.91	9.7	300
.187	317.8	2.96	10.0	300
1913.17	317.4	2.94		

AC

1913.157	276.0	7.84	9.8	240
.184	275.8	8.06	9.9	240
.187	275.9	7.94	9.9	240
1913.18	275.9	7.95		

Hu. 1486. C.P.D. —54° 4788

R.A. 11h 43m 18s; Decl. —54° 48'.8
(8.5 . . . 9.2)

1913.157	76.9	2.52	10.0	240
.184	79.5	2.40	9.2	300
.187	76.2	2.64	9.5	670
1913.18	77.5	2.52		

Hu. 1487. C.P.D. —55° 4673

R.A. 11h 44m 41s; Decl. —55° 11'.6
(8.8 . . . 10.0)

1913.157	238.4	1.32	10.1	300
.184	240.3	1.23	9.4	240
.187	237.9	1.32	9.7	670
1913.18	238.9	1.29		

Hu. 1488. C.P.D. — 57° 5105

R.A. 11h 49m 29s; Decl. — 57° 17′.4
(8.8 . . . 10.5)

1913.107	17.8	3.46	9.9	300
.144	16.4	3.20	9.5	300
.151	16.2	3.23	9.3	300
1913.14	16.8	3.30		

Hu. 1489. C.P.D. — 21° 5116

R.A. 11h 49m 32s; Decl. — 21° 29′.2
(8.0 . . . 12.0) pr. 1″.5

Hu. 1490. C.P.D. — 24° 4754

R.A. 11h 50m 41s; Decl. — 24° 47′.1
(8.5 . . . 8.5)

1913.277	82.9	0.68	10.0	670

Hu. 1491. C.P.D. — 56° 4994

R.A. 11h 58m 18s; Decl. — 56° 30′.1
(8.5 . . . 9.2)

1913.144	320.7	0.91	9.8	300
.151	318.0	0.88	9.8	300
1913.15	319.4	0.89		

Hu. 1492. C.P.D. — 25° 4872

R.A. 11h 59m 36s; Decl. — 25° 5′.7
(9.0 . . . 9.5) 100° 0″.5

Hu. 1493. C.P.D. — 44° 5873

R.A. 12h 5m 17s; Decl. — 44° 22′.5
(9.5 . . . 9.5)

1913.238	142.6	0.65	9.7	300
.241	146.3	0.88	9.7	300
1913.24	144.5	0.77		

Hu. 1494. C.P.D. — 42° 5907

R.A. 12h 32m 44s; Decl. — 42° 17′.8
(9.2 . . . 9.2)

1913.261	145.7	1.18	10.0	670

Hu. 1495. C.P.D. — 55° 5184

R.A. 12h 34m 33s; Decl. — 55° 12′.1
(9.5 . . . 9.5)

1913.151	274.9	0.95	10.3	300

Hu. 1496. C.P.D. — 44° 6046

R.A. 12h 37m 08s; Decl. — 44° 18′.0
(8.8 . . . 13.0)

1913.261	314.9	2.72	10.2	300

Hu. 1497. C.P.D. — 25° 4995

R.A. 12h 37m 43s; Decl. — 25° 23′.1
(9.0 . . . 10.0)

1913.258	341.5	1.61	10.1	300
.277	342.2	1.89	10.7	300
1913.27	341.9	1.75		

Hu. 1498. C.P.D. — 43° 5902

R.A. 12h 41m 50s; Decl. — 43° 24′.2
(8.5 . . . 12.0)

1913.261	262.4	5.10	10.5	300

Hu. 1499. C.P.D. — 44° 6107

R.A. 12h 45m 20s; Decl. — 44° 48′.7
(9.2 . . . 9.2)

1913.261	293.9	1.42	10.7	670

Hu. 1500. C.P.D. — 23° 5703

R.A. 13h 04m 04s; Decl. — 23° 30′.7
(7.5 . . . 11.8)

1913.258	31.1	3.55	10.5	300
.277	30.0	3.68	11.2	300
1913.27	30.6	3.62		

Hu. 1501. C.P.D. — 24° 5022

R.A. 13h 08m 13s; Decl. — 24° 13′.6
(9.0 . . . 9.0) 30° 0″.3

Hu. 1502. C.P.D. — 25° 5153

R.A. 13h 12m 51s; Decl. — 25° 13′.2
(9.0 . . . 10.0) 70° 1″

Hu. 1503. C.P.D. — 22° 5590

R.A. 13h 58m 36s; Decl. — 22° 08′.4
(7.2 . . . 10.5)

1913.258	196.7	0.90	11.0	670

Hu. 1504. C.P.D. — 45° 6669

R.A. 13h 55m 51s; Decl. — 45° 42′.0
(9.0 . . . 10.0)

1913.261	143.4	3.08	11.4	300
.294	144.2	2.82	10.9	300
1913.28	143.8	2.95		

Hu. 1505. C.P.D. — 42° 6519

R.A. 13h 56m 23s; Decl. — 42° 48′.1
(9.0 . . . . 9.4)

1913.261	126.7	2.43	11.1	300
.294	125.9	2.45	10.8	300
1913.28	126.3	2.44		

Hu. 1506. C.P.D. —44° 6659

R.A. 14^h 01^m 10^s; Decl. —44° 58′.9
(8.7 . . . 10.0 . . . 11.0)

	AB			
1913.261	258.4	37.45	11.5	300
	BC			
1913.261	32.7	4.39	11.5	300
.294	32.3	4.11	11.0	300
1913.28	32.5	4.25		

Hu. 1507. C.P.D. —43° 6503

R.A. 14^h 12^m 50^s; Decl. —43° 48′.8
(8.5 . . . 9.5)

1913.261	83.2	2.87	11.8	300
.294	83.3	2.87	11.4	300
.624	85.7	2.50	18.3	300
1913.39	84.1	2.75		

Hu. 1508. C.P.D. —45° 6879

R.A. 14^h 23^m 57^s; Decl. —45° 32′.5
(8.7 . . . 12.0)

1913.261	314.1	5.96	12.0	300
.294	312.8	5.98	11.9	300
1913.28	313.5	5.97		

Hu. 1509. C.P.D. —45° 6910

R.A. 14^h 27^m 19^s; Decl. —45° 26′.3
(8.1 . . . 11.3)

1913.261	233.8	2.01	12.2	300
.294	236.7	1.60	12.0	670
1913.28	235.2	1.80		

Hu. 1510. C.P.D. —43° 6650

R.A. 14^h 33^m 36^s; Decl. —43° 42′.2
(9.0 . . . 9.5)

1913.261	139.4	0.76	12.3	670

Hu. 1511. C.P.D. —24° 5376

R.A. 14^h 41^m 01^s; Decl. —24° 05′.3
(9.0 . . . 9.5)

1913.258	312.1	1.06	12.5	670
.277	309.2	0.90	12.5	670
1913.27	310.7	0.98		

Hu. 1512. C.P.D. —23° 5987

R.A. 14^h 42^m 04^s; Decl. —23° 10′.0
(9.0 . . . 9.0)

1913.258	51.0	1.06	12.7	670
.277	48.6	1.00	12.6	670
1913.27	49.8	1.03		

Hu. 1513. C.P.D. —42° 6913

R.A. 14^h 59^m 17^s; Decl. —42° 37′.3
(8.8 . . . 9.3)

1913.294	180.9	2.31	12.7	670
.624	181.7	1.93	18.6	300
1913.46	181.3	2.12		

Hu. 1514. C.P.D. —41° 7146

R.A. 15^h 12^m 10^s; Decl. —41° 58′.9
(8.8 . . . 9.5)

1913.294	252.2	2.74	12.8	670

Hu. 1515. C.P.D. —24° 5501

R.A. 15^h 12^m 52^s; Decl. —24° 31′.3
(8.5 . . . 12.0)

1913.258	153.9	1.94	13.1	300
.277	158.1	1.98	13.5	300
1913.27	156.0	1.96		

Hu. 1516. C.P.D. —22° 6064

R.A. 15^h 37^m 01^s; Decl. —22° 56′.4
(9.0 . . . 10.0)

1913.258	248.4	1.48	13.3	300
.277	248.2	1.61	13.7	300
1913.27	248.3	1.54		

Hu. 1517. C.P.D. —45° 8030

R.A. 16^h 26^m 58^s; Decl. —45° 22′.0
(10.0 . . . 11.0) 90° 0″.5

Hu. 1518. C.P.D. —44° 7988

R.A. 16^h 30^m 19^s; Decl. —44° 38′.0
(8.6 . . . 10.0) 250° 1″

Hu. 1519. C.P.D. —42° 7476

R.A. 16^h 33^m 52^s; Decl. —42° 38′.5
(9.0 . . . 10.0)

1913.294	73.0	1.06	13.0	670
.441	75.5	1.17	13.8	300
1913.37	74.3	1.12		

Hu. 1520. C.P.D. —45° 8134

R.A. 16^h 38^m 27^s; Decl. —45° 13′.9
(8.5 . . . 8.5)

1913.258	175.0	0.44	13.7	670

Hu. 1521. C.P.D. —44° 8253

R.A. 16^h 59^m 20^s; Decl. —44° 33′.0
(9.0 . . . 12.0) 190° 3″

Hu. 1522. C.P.D. —25° 5949

R.A. $17^h\ 03^m\ 54^s$; Decl. —25° 08′.6
(9.0 . . . 10.0) 270° 1″

Hu. 1523. C.P.D. —43° 8026

R.A. $17^h\ 15^m\ 10^s$; Decl. —43° 40′.9
(8.0 . . . 11.0)

1913.441	267.0	7.26	14.5	300
.709	266.7	7.43	21.1	300
1913.57	266.8	7.35		

Hu. 1524. C.P.D. —22° 6446

R.A. $17^h\ 40^m\ 27^s$; Decl. —22° 36′.7
(9.5 . . . 9.5) 330° 1″

Hu. 1525. C.P.D. —46° 9068

R.A. $17^h\ 55^m\ 10^s$; Decl. —46° 26′.9
(8.0 . . . 9.5) 270° 0″.8

Hu. 1526. C.P.D. —46° 9332

R.A. $18^h\ 20^m\ 08^s$; Decl. —46° 23′.1
(9.0 . . . 9.0) 30° 1″.5

Hu. 1527. C.P.D. —45° 9398

R.A. $18^h\ 30^m\ 14^s$; Decl. —45° 51′.3
(8.0 . . . 11.0)

1913.439	310.7	4.70	16.3	300
.710	311.2	4.58	23.1	300
1913.67	311.0	4.64		

Hu. 1528. C.P.D. —47° 9026

R.A. $18^h\ 35^m\ 02^s$; Decl. —47° 04′.8
(8.7 . . . 11.0) 220° 1″.5

Hu. 1529. C.P.D. —41° 9137

R.A. $19^h\ 26^m\ 30^s$; Decl. —41° 41′.5
(9.0 . . . 10.0)

1913.439	305.5	1.99	16.9	300
.710	304.6	2.32	0.2	300
.792	303.9	2.08	23.9	300
1913.65	304.7	2.13		

Hu. 1530. C.P.D. —46° 9768

R.A. $19^h\ 31^m\ 23^s$; Decl. —46° 58′.3
(9.0 . . . 9.5) 200° 0″.8

Hu. 1531. C.P.D. —54° 9663

R.A. $20^h\ 09^m\ 31^s$; Decl. —54° 55′.7
(9.5 . . . 9.5) 180° 2″

Hu. 1532. C.P.D. —54° 9711

R.A. $20^h\ 23^m\ 52^s$; Decl. —54° 17′.3
(9.0 . . . 10.5)

1913.814	279.5	0.86	24.0	400
.836	280.7	0.69	0.7	400
1913.82	280.1	0.77		

Hu. 1533. C.P.D. —45° 10067

R.A. $20^h\ 51^m\ 59^s$; Decl. —45° 48′.1
(8.8 . . . 11.0)

1913.792	52.6	4.77	0.9	300
.819	53.4	4.51	0.7	400
1913.81	53.0	4.64		

Hu. 1534. C.P.D. —56° 9604

R.A. $21^h\ 05^m\ 01^s$; Decl. —56° 45′.9
(7.8 . . . 12.2)

1913.814	345.4	5.17	1.5	300
.828	342.1	5.24	1.3	400
.831	344.0	5.49	1.7	300
1913.82	343.8	5.30		

Hu. 1535. C.P.D. —56° 9606

R.A. $21^h\ 05^m\ 21^s$; Decl. —56° 22′.3
(8.5 . . . 12.0) 225° 8″

Hu. 1536. C.P.D. —56° 9630

R.A. $21^h\ 13^m\ 30^s$; Decl. —56° 18′.7
(7.5 . . . 12.0)

1913.803	171.3	6.03	1.5	400
.831	172.2	5.64	1.8	300
.836	172.3	5.81	1.3	300
1913.82	171.9	5.83		

Hu. 1537. C.P.D. —55° 9581

R.A. $21^h\ 15^m\ 27^s$; Decl. —55° 06′.4
(8.5 . . . 12.0)

1913.836	351.7	3.63	1.6	300

Hu. 1538. C.P.D. —48° 10598

R.A. $21^h\ 24^m\ 42^s$; Decl. —48° 10′.6
(8.8 . . . 12.0)

1913.819	303.5	1.33	2.4	400

Hu. 1539. C.P.D. —45° 10160

R.A. $21^h\ 46^m\ 23^s$; Decl. —45° 12′.2
(9.0 . . . 9.5)

1913.690	84.1	1.33	19.3	300
.710	84.0	1.57	1.5	300
.792	85.5	1.23	1.0	300
.819	82.9	1.61	0.9	400
1913.75	84.1	1.44		

Hu. 1540. C.P.D. —46° 10270

R.A. $21^h\ 32^m\ 39^s$; Decl. —46° 44'.9
(8.5 . . . 11.5)

1913.690	309.9	3.02	19.5	300
.819	309.7	3.24	2.6	400
.833	307.7	3.18	1.0	300
1913.78	309.1	3.15		

Hu. 1541. C.P.D. —49° 11495

R.A. $21^h\ 40^m\ 14^s$; Decl. —49° 25'.5
(8.5 . . . 11.0)

1913.792	100.0	5.88	2.5	300
.819	100.1	5.63	...	400
.833	100.6	5.66	...	300
1913.81	100.2	5.72		

Hu. 1542. C.P.D. —54° 9951

R.A. $21^h\ 57^m\ 44^s$; Decl. —54° 29'.2
(9.0 . . . 12.0) 120° 6"

Hu. 1543. C.P.D. —57° 10042

R.A. $22^h\ 00^m\ 14^s$; Decl. —57° 02'.7
(8.2 . . . 8.2) ... 0".8

Hu. 1544. C.P.D. —54° 10202

R.A. $22^h\ 27^m\ 20^s$; Decl. —54° 15'.2
(9.2 . . . 10.0)

1913.803	149.2	0.79	2.2	400

Hu. 1545. C.P.D. —45° 10338

R.A. $22^h\ 41^m\ 02^s$; Decl. —45° 54'.5
(8.0 . . . 9.0)

1913.690	40.3	1.33	20.1	300
.710	45.1	1.27	2.0	300
.792	41.9	1.35	1.7	670
1913.73	42.4	1.32		

Hu. 1546. C.P.D. —55° 9937

R.A. $22^h\ 54^m\ 31^s$; Decl. —55° 56'.2
(8.5 . . . 10.0) 100° 1"

Hu. 1547. C.P.D. —48° 10854

R.A. $22^h\ 59^m\ 12^s$; Decl. —48° 27'.5
(7.8 . . . 10.5)

1913.690	155.8	3.11	20.9	300
.819	154.3	2.94	3.9	400
.833	156.1	2.89	1.7	400
1913.78	155.4	2.98		

Hu. 1548. C.P.D. —55° 9961

R.A. $23^h\ 02^m\ 37^s$; Decl. —55° 18'.0
(8.6 . . . 11.0) 270° 2"

Hu. 1549. C.P.D. —54° 10225

R.A. $23^h\ 05^m\ 40^s$; Decl. —54° 52'.0
(7.0 . . . 9.0) ... 1"

Hu. 1550. C.P.D. —42° 9601

R.A. $23^h\ 34^m\ 28^s$; Decl. —42° 16'.9

1913.792	181.5	0.63	1.9	670

ANN ARBOR, MICHIGAN,
May 4, 1914.

DOUBLE STARS DISCOVERED AT LA PLATA.

BY W. J. HUSSEY.

Fourteenth Catalogue

The double stars of this catalogue were discovered and measured with the 17-inch Gautier refractor of the La Plata Observatory. Prior to February 11, 1914, the measures were made with the micrometer belonging to the small equatorial and those subsequent to that date with the new filar micrometer, furnished by The Warner & Swasey Company. In nearly all cases each position angle given is derived from the mean of four settings of the circle and each recorded distance from the mean of three measures of the double distance. The right ascensions and declinations are for the epoch 1875.0. In the measures, the last two columns contain the sidereal times of observation and the powers used.

ANN ARBOR, MICHIGAN.
FEBRUARY, 27, 1915.

Hu. 1551. C.P.D. —53° 9

R.A. $0^h\ 2^m\ 26^s$; Decl. —53° 1'.4
(8.0 . . . 11.5)

1914.687	126°.8	8".27	$21^h.3$	360

Hu. 1552. C.P.D. —51° 28

R.A. $0^h\ 9^m\ 17^s$; Decl. —51° 0'.1
(9.5 . . . 9.8)

1914.687	66.6	2.04	22.0	360

Hu. 1553. C.P.D. —59° 114

R.A. $1^h\ 34^m\ 25^s$; Decl. —59° 12'.9
(8.8 . . . 9.0)

1914.882	370.0	1.81	5.5	360

Hu. 1554. C.P.D. —54° 369

R.A. 1^h 38^m 16^s; Decl. —54° 51′.9
(9.0 . . . 9.2)

1914.764	281.8	5.71	23.3	360
.775	281.6	5.62	22.9	360
1914.77	281.7	5.67		

Hu. 1555. C.P.D. —57° 355

R.A. 1^h 42^m 40^s; Decl. —57° 4′.4
(9.1 . . . 9.8)

1914.764	91.6	8.74	23.5	360
.775	90.4	8.73	23.2	360
1914.77	91.0	8.74		

Hu. 1556. C.P.D. —56° 257

R.A. 1^h 51^m 57^s; Decl. —51° 5′0
(9.5 . . . 10.5)

1914.756	329.7	0.68	22.8	450

Hu. 1557. C.P.D. —54° 401

R.A. 1^h 54^m 5^s; Decl. —54° 8′.1
(9.2 . . . 10.5)

1914.764	105.6	2.33	23.0	360
.774	110.4	2.22	23.4	360
1914.77	108.0	2.27		

Hu. 1558. C.P.D. —54° 409

R.A. 1^h 56^m 40^s; Decl. —54° 36′.9
(8.3 . . . 11.5)

1914.764	51.6	3.95	22.8	360

Hu. 1559. C.P.D. —51° 267

R.A. 1^h 57^m 41^s; Decl. —51 ° 20′.6
(9.2 . . . 9.5)

1914.756	313.0	1.00	23.7	360

Hu. 1560. C.P.D. —55° 393

R.A. 2^h 4^m 4^s; Decl. —55° 26′.6
(8.8 . . . 9.2)

1914.775	94.6	0.58	23.7	360

Hu. 1561. C.P.D. —24° 321

R.A. 2^h 41^m 47^s; Decl. —24° 12′.2
(9.0 . . . 9.5)

1914.750	312.7	0.91	0.0	360

Hu. 1562. C.P.D. —53° 489

R.A. 2^h 47^m 49^s; Decl. —53° 4′.4
(8.8 . . . 8.8)

1914.761	59.0	0.52	0.1	450

Hu. 1563. C.P.D. —50° 408

R.A. 2^h 48^m 46^s; Decl. —50° 10′.9
(9.0 . . . 11.0)

1914.756	8.0	2.66	0.3	360

Hu. 1564. C.P.D. —51° 393

R.A. 3^h 15^m 41^s; Decl. —51° 0′.1
(9.0 . . . 9.5)

1914.775	244.6	1.62	1.0	360

Hu. 1565. C.P.D. —53° 554

R.A. 3^h 17^m 40^s; Decl. —53° 52′.8
(9.2 . . . 9.2)

1914.775	103.7	1.76	0.6	360

Hu. 1566. C.P.D. —51° 730

R.A. 5^h 30^m 38^s; Decl. —51° 9′.1
(9.5 . . . 9.5)

1914.978	175.2	0.76	2.8	360

Hu. 1567. C.P.D. —61° 491

R.A. 5^h 36^m 40^s; Decl. —61° 33′.8
(8.6 . . . 9.2)

1914.948	58.3	0.98	2.1	450
.956	58.4	0.87	2.3	360
1914.95	58.4	0.93		

Hu. 1568. C.P.D. —50° 826

R.A. 5^h 38^m 43^s; Decl. —50° 4′.1
(8.8 . . . 9.0)

1914.975	48.4	0.58	2.8	450
.978	46.6	0.57	3.3	450
1914.98	47.5	0.58		

Hu. 1569. C.P.D. —50° 829

R.A. 5^h 40^m 29^s; Decl. —50° 31′.1
(9.0 . . . 10.2)

1914.975	71.2	1.13	2.6	360
978	71.4	1.07	3.0	450
1914.98	71.3	1.10		

Hu. 1570. C.P.D. —52° 814

R.A. 5^h 55^m 13^s; Decl. —52° 12′.9
(9.0 . . . 9.2)

1914.975	36.2	0.82	3.6	360
.978	37.1	0.82	3.6	360
1914.98	36.7	0.82		

Hu. 1571. C.P.D. —50° 878

R.A. 5h 55m 58s; Decl. —50° 41′.3
(9.0 . . . 11.0)

1914.975	157.5	0.73	3.4	360

Hu. 1572. C.P.D. —52° 852

R.A. 6h 3m 31s; Decl. —52° 18′.3
(8.6 . . . 8.6)

1914.972	49.0	0.43	3.2	450
.975	46.9	0.57	4.0	450
1914.97	48.0	0.50		

Hu. 1573. C.P.D. —52° 867

R.A. 6h 6m 0s; Decl. —52° 6′.9
(8.2 . . . 8.8)

1914.972	182.6	0.22	3.3	450

Hu. 1574. C.P.D. —51° 871

R.A. 6h 11m 19s; Decl. —51° 32′.8
(9.2 . . . 12.0)

1914.972	234.1	1.07	3.5	360

Hu. 1575. C.P.D. —61° 630

R.A. 6h 18m 39s; Decl. —61° 28′.6
(8.3 . . . 10.5)

1914.956	248.0	1.12	2.8	360
.961	242.9	1.31	2.7	450
.964	245.9	0.96	3.9	450
1914.96	245.6	1.13		

Hu. 1576. C.P.D. —58° 712

R.A. 6h 26m 29s; Decl. —58° 16′.2
(9.1 . . . 9.1)

1914.956	48.6	0.49	3.7	360
.963	52.6	0.44	2.9	450
1914.96	50.6	0.47		

Hu. 1577. C.P.D. —61° 684

R.A. 6h 35m 0s; Decl. —61° 29′.2
(8.8 . . . 12.5)

1914.956	141.4	2.58	3.3	360
.963	142.7	2.78	3.0	360
1914.96	142.0	2.68		

Hu. 1578. C.P.D. —53° 1159

R.A. 6h 44m 39s; Decl. —53° 25′.0
(9.5 . . . 9.5)

1914.972	138.3	1.05	4.4	360

Hu. 1579. C.P.D. —59° 725

R.A. 6h 53m 44s; Decl. —59° 22′.1
(9.0 . . . 9.2)

1914.961	33.4	1.10	4.3	360
.964	31.4	1.08	4.6	450
1914.96	32.4	1.09		

Hu. 1580. C.P.D. —61° 749

R.A. 6h 56m 29s; Decl. —61° 21′.0
(8.8 . . . 9.0)

1914.961	12.2	0.54	3.9	360
.964	7.7	0.64	4.5	450
1914.96	10.0	0.59		

Hu. 1581. C.P.D. —52° 1081

R.A. 7h 4m 0s; Decl. —52° 16′.9
(8.4 . . . 10.5)

1914.972	54.4	1.30	4.7	360
1915.027	58.5	1.00	4.8	360
1915.00	56.5	1.15		

Hu. 1582. C.P.D. —59° 776

R.A. 7h 6m 8s; Decl. —59° 26′.7
(9.0 . . . 11.8)

1914.961	215.5	6.62	4.7	360
.964	214.9	6.54	4.7	450
1914.96	215.2	6.58		

Hu. 1583. C.P.D. —59° 873

R.A. 7h 39m 14s; Decl. —59° 42′.4
(8.2 . . . 8.4)

1914.942	243.1	1.06	4.2	360
.956	240.0	0.90	5.1	450
.959	242.9	0.90	4.9	360
1914.95	242.0	0.95		

Hu. 1584. C.P.D. —59° 881

R.A. 7h 40m 19s; Decl. —59° 8′.6
(8.5 . . . 11.2)

1914.942	318.0	....	4.4	360
.956	319.0	2.78	4.9	360
.959	320.1	2.85	5.1	360
1914.95	319.0	2.82		

Hu. 1585. C.P.D. —58° 986

R.A. 7h 43m 15s; Decl. —58° 38′.9
(8.0 . . . 12.2)

1914.956	71.2	1.62	4.7	450
.959	66.7	1.64	5.2	360
1914.96	69.0	1.63		

Hu. 1586. C.P.D. — 52° 1284

R.A. $7^h\ 44^m\ 32^s$; Decl. — 52° 51′.9

(9.0 . . . 9.4)

1914.972	266.0	2.33	5.2	360
.975	262.4	2.36	4.4	360
1915.027	265.4	2.17	5.3	360
1914.99	264.6	2.29		

Hu. 1587. C.P.D. — 53° 1473

R.A. $7^h\ 51^m\ 12^s$; Decl. — 53° 38′.9

(9.2 . . . 9.8)

1914.975	293.7	2.18	4.5	360
1915.027	293.2	1.90	5.3	360
1915.00	293.5	1.99		

Hu. 1588. C.P.D. — 50° 1722

R.A. $8^h\ 37^m\ 26^s$; Decl. — 50° 11′.6

(9.0 . . . 11.0)

1914.967	66.4	1.18	5.3	360
.972	70.6	1.08	6.1	360
1914.97	68.5	1.13		

Hu. 1589. C.P.D. — 52° 1648

R.A. $8^h\ 42^m\ 38^s$; Decl. — 52° 40′.3

(8.2 . . . 11.8)

1914.967	93.1	3.34	6.0	360
.972	91.8	3.34	6.5	450
1914.97	92.5	3.34		

Hu. 1590. C.P.D. — 52° 1652

R.A. $8^h\ 42^m\ 44^s$; Decl. — 52° 23′.1

(7.8 . . . 8.3)

1914.967	333.9	0.36	5.7	450
.972	336.8	0.33	6.3	450
1914.97	335.4	0.35		

Hu. 1591. C.P.D. — 59° 1121

R.A. $8^h\ 44^m\ 46^s$; Decl. — 59° 9′.5

(8.0 . . . 12.5)

1914.959	222.4	5.52	6.1	360
.964	222.1	5.46	6.2	360
1914.96	222.3	5.49		

Hu. 1592 C.P.D. — 58° 1625

R.A. $9^h\ 41^m\ 26^s$; Decl. — 58° 53′.9

(8.0 . . . 11.2)

1914.956	285.1	2.57	6.3	360
.959	288.5	2.47	6.6	360
1914.96	286.8	2.52		

Hu. 1593. C.P.D. — 61° 1441

R.A. $9^h\ 59^m\ 43^s$; Decl. — 61° 16′.6

(7.5 . . . 7.8)

1914.956	349.0	1.23	7.5	450
.959	349.7	1.30	6.8	360
1914.96	349.4	1.27		

Hu. 1594. C.P.D. — 50° 3018

R.A. $10^h\ 0^m\ 20^s$; Decl. — 50° 42′.5

(7.0 . . . 7.0)

1914.967	82.9	0.23	6.9	450
1915.027	76.7	0.23	7.3	450
1915.00	79.8	0.23		

Hu. 1595. C.P.D. — 61° 1477

R.A. $10^h\ 3^m\ 35^s$; Decl. — 61° 37′.7

(7.8 . . . 11.8)

1914.959	136.7	2.91	6.9	360
.964	140.4	3.01	7.2	360
1914.96	138.6	2.96		

Hu. 1596. C.P.D. — 58° 2031

R.A. $10^h\ 10^m\ 53^s$; Decl. — 58° 8′.8

(9.0 . . . 9.5)

1914.964	338.1	1.17	7.7	360

Hu. 1597. C.P.D. — 59° 2008

R.A. $10^h\ 11^m\ 47^s$; Decl. — 59° 16′.8

(7.5 . . . 7.5)

1914.956	114.2	0.26	7.5	450
.959	117.2	0.27	7.2	670
1914.96	115.7	0.26		

Hu. 1598. C.P.D. — 50° 3316

R.A. $10^h\ 13^m\ 18^s$; Decl. — 50° 11′.8

(8.2 . . . 8.5)

1914.967	245.5	0.42	7.2	450
1915.027	242.7	0.41	7.5	450
1915.00	244.1	0.42		

Hu. 1599. C.P.D. — 60° 1881

R.A. $10^h\ 19^m\ 24^s$; Decl. — 60° 56′.1

(8.6 . . . 9.5)

1914.959	359.8	1.24	7.5	360

Hu. 1600. C.P.D. — 51° 3645

R.A. $10^h\ 46^m\ 59^s$; Decl. — 51° 31′4

(8.0 . . . 11.0)

1914.967	334.6	1.75	7.8	360
.972	331.7	1.95	7.4	360
1914.97	343.2	1.85		

Hu. 1601. C.P.D. — 53° 4262

R.A. $10^h\ 52^m\ 47^s$; Decl. — 53° 39′.8
(9.5 . . . 9.5)

1914.972	165.4	0.21	8.1	450

Hu. 1602. C.P.D. — 57° 4384

R.A. $11^h\ 5^m\ 28^s$; Decl. — 57° 32′.2
(9.2 . . . 9.8)

1913.107	95.6	3.94	8.8	300
.122	94.8	3.84	9.2	300
.151	95.0	3.97	9.6	300
1913.13	95.1	3.92		

Hu. 1603. C.P.D. — 60° 3300

R.A. $11^h\ 39^m\ 47^s$; Decl. — 60° 13′.5
(9.5 . . . 10.5)

1914.964	42.4	1.70	8.7	360

Hu. 1604. C.P.D. — 52° 5302

R.A. $12^h\ 4^m\ 34^s$; Decl. — 52° 20′.5
(9.2 . . . 9.2)

1914.972	101.2	0.40	9.4	450

Hu. 1605. C.P.D. — 57° 8070

R.A. $16^h\ 24^m\ 55^s$; Decl. — 57° 48′.9
(8.8 . . . 9.5)

1914.695	73.2	4.25	20.0	360
.706	72.8	4.35	20.0	360
1914.70	73.0	4.30		

Hu. 1606. C.P.D. — 54° 7853

R.A. $16^h\ 39^m\ 4^s$; Decl. — 54° 26′.8
(8.8 . . . 9.5)

1914.720	171.9	1.86	20.7	360

Hu. 1607. C.P.D. — 51° 10928

R.A. $18^h\ 25^m\ 23^s$; Decl. — 51° 25′.3
(9.0 . . . 11.5)

1914.819	266.9	2.34	22.6	360

Hu. 1608. C.P.D. — 52° 11520

R.A. $19^h\ 35^m\ 7^s$; Decl. — 52° 27′.6
(8.4 . . . 8.8)

1914.817	251.1	0.38	23.7	450
.858	253.8	0.35	23.8	450
1914.87	252.5	0.37		

Hu. 1609. C.P.D. — 63° 4554

R.A. $19^h\ 46^m\ 39^s$; Decl. — 63° 0′.2
(9.0 . . . 12.0)

1914.849	250.4	2.30	0.2	360
.852	251.3	2.05	0.2	360
1914.85	250.8	2.18		

Hu. 1610. C.P.D. — 52° 11593

R.A. $19^h\ 49^m\ 22^s$; Decl. — 52° 27′.7
(8.8 . . . 11.0)

1914.583	155.8	1.74	17.2	360
.817	154.3	2.08	0.4	450
.858	155.6	2.04	23.9	450
1914.75	155.2	1.95		

Hu. 1611. C.P.D. — 62° 6142

R.A. $19^h\ 58^m\ 15^s$; Decl. — 62° 31′.5
(9.0 . . . 11.5)

1914.849	299.8	1.60	0.9	360
.852	300.8	1.61	0.6	360
1914.85	300.3	1.60		

Hu. 1612. C.P.D. — 50° 11284

R.A. $20^h\ 0^m\ 14^s$; Decl. — 50° 48′.0
(8.8 . . . 9.5)

1914.585	57.9	0.87	18.0	360
.858	58.6	0.96	0.1	450
1914.72	58.3	0.92		

Hu. 1613. C.P.D. — 50° 11306

R.A. $20^h\ 4^m\ 40^s$; Decl. — 50° 41′.5
(8.5 . . . 8.5)

1914.585	310.8	0.56	17.5	670
.858	309.7	0.79	0.2	450
1914.72	310.3	0.67		

Hu. 1614. C.P.D. — 52° 11649

R.A. $20^h\ 7^m\ 3^s$; Decl. — 52° 55′.9
(8.5 . . . 12.5)

1914.858	78.0	1.26	1.6	360

Hu. 1615. C.P.D. — 63° 4590

R.A. $20^h\ 23^m\ 53^s$; Decl. — 63° 44′.1
(7.5 . . . 8.0)

1914.852	359.4	0.39	1.3	450
.873	358.2	0.46	0.7	450
1914.86	358.8	0.43		

Hu. 1616. C.P.D. —64° 4063

R.A. 20h 29m 48s; Decl. —64° 37′.1
(8.4 . . . 9.0)

1914.873	83.3	0.77	1.0	450

Hu. 1617. C.P.D. —51° 11541

R.A. 20h 31m 8s; Decl. —51° 39′.8
(8.0 . . . 8.8)

1914.585	124.1	0.53	18.5	360
.858	124.2	0.43	1.3	450
1914.72	124.2	0.48		

Hu. 1618. C.P.D. —51° 11553

R.A. 20h 36m 28s; Decl. —51° 32′.2
(8.5 . . . 10.5)

1914.583	229.9	0.92	18.2	360
.646	234.2	0.98	18.0	475
.649	234.8	1.03	18.5	360
1914.63	233.0	0.98		

Hu. 1619. C.P.D. —58° 7776

R.A. 20h 37m 6s; Decl. —58° 44′.9
(9.0 . . . 12.5)

1914.835	35.6	1.13	23.8	360
.844	36.6	1.05	23.7	360
1914.84	36.1	1.09		

Hu. 1620. C.P.D. —64° 4074

R.A. 20h 38m 8s; Decl. —64° 20′.0
(8.8 . . . 10.0)

1914.873	278.0	1.52	1.4	360

Hu. 1622. C.P.D. —61° 6510

R.A. 20h 41m 25s; Decl. —61° 52′.8
(8.4 . . . 11.5)

1914.841	299.3	1.31	1.6	360
.844	298.1	1.57	23.8	360
1914.84	298.7	1.44		

Hu. 1623. C.P.D. —52° 11777

R.A. 20h 41m 29s; Decl. —52° 45′.4
(8.2 . . . 12.0)

1914.583	243.7	1.52	17.8	360
.858	247.0	1.57	1.4	360
1914.72	245.4	1.55		

Hu. 1624. C.P.D. —59° 7657

R.A. 20h 47m 32s; Decl. —59° 32′.9
(8.5 . . . 8.8)

1914.841	262.8	4.05	1.7	360
.844	262.8	4.03	0.2	450
1914.84	262.8	4.04		

Hu. 1625. C.P.D. —58° 7805

R.A. 20h 56m 16s; Decl. —58° 13′.8
(8.5 . . . 9.0)

1914.835	230.7	0.59	0.3	450
.841	228.9	0.60	2.1	450
.844	229.5	0.60	0.4	450
1914.84	229.7	0.60		

Hu. 1626. C.P.D. —52° 10827

R.A. 21h 2m 29s; Decl. —52° 50′.8
(7.5 . . . 8.0)

1914.635	205.4	0.72	19.3	670
.858	209.9	0.56	1.9	360
1914.75	207.7	0.64		

Hu. 1627. C.P.D. —58° 7816

R.A. 21h 2m 34s; Decl. —58° 8′.0
(8.8 . . . 9.0)

1914.835	198.1	1.43	1.3	450
.841	196.5	....	....	450
.844	198.3	1.50	0.6	
1914.84	197.6	1.47		

Hu. 1628. C.P.D. —59° 7689

R.A. 21h 9m 32s; Decl. —59° 19′.9
(8.5 . . . 9.0)

1914.835	271.2	1.05	1.1	450
.844	271.1	0.92	0.7	450
1914.84	271.2	0.98		

Hu. 1629. C.P.D. —52° 11878

R.A. 21h 19m 41s; Decl. —52° 24′.4
(8.8 . . . 9.2)

1914.583	258.7	1.29	18.8	360
.618	258.7	1.35	18.6	360
.649	253.9	0.95	18.9	360
1914.62	257.1	1.20		

Hu. 1630. C.P.D. —61° 6559

R.A. 21h 20m 52s; Decl. —61° 0′.6
(8.8 . . . 9.5)

1914.835	234.1	2.70	2.0	450
.844	233.3	2.71	1.6	450
.847	236.8	2.83	0.8	450
1914.84	234.7	2.78		

Hu. 1631. C.P.D. —60° 7484

R.A. 21^h 22^m 52^s; Decl. —60° 8'.4

(9.0 . . . 9.4)

1914.835	200.9	1.44	1.8	450
.847	206.6	1.24	0.8	450
1914.84	203.8	1.34		

Hu. 1632. C.P.D. —52° 11908

R.A. 21^h 30^m 8^s; Decl. —52° 1'.3

(8.8 . . . 13.0)

1914.817	181.4	1.31	1.3	450

Hu. 1633. C.P.D. —57° 9965

R.A. 21^h 41^m 51^s; Decl. —57° 21'.8

(9.5 . . . 9.5)

1913.836	137.2	1.52	1.7	300

Hu. 1634. C.P.D. —60° 7512

R.A. 21^h 42^m 33^s; Decl. —60° 0'.3

(8.5 . . . 10.5)

1914.838	249.4	2.40	1.9	360
.847	252.7	2.32	1.5	450
1914.84	251.0	2.36		

Hu. 1635. C.P.D. —50° 11634

R.A. 21^h 51^m 40^s; Decl. —50° 50'.4

(8.7 . . . 12.0)

1914.817	264.6	1.02	2.0	360

Hu. 1636. C.P.D. —62° 6311

R.A. 22^h 4^m 7^s; Decl. —62° 35'.8

(8.8 . . . 11.0)

1914.852	293.4	2.66	2.8	360
.873	292.1	2.72	2.5	360
1914.86	292.7	2.69		

Hu. 1637. C.P.D. —61° 6626

R.A. 22^h 4^m 15^s; Decl. —61° 49'.1

(8.5 . . . 10.0)

1914.847	192.9	5.23	2.3	360

Hu. 1638. C.P.D. —52° 12002

R.A. 22^h 9^m 8^s; Decl. —52° 35'.9

(8.0 . . . 9.5)

1914.585	93.1	2.80	19.3	360
.618	91.1	2.56	19.4	360
.635	95.6	2.54	19.3	360
1914.61	93.3	2.63		

Hu. 1639. C.P.D. —50° 11698

R.A. 22^h 16^m 31^s; Decl. —50° 42'.4

(9.0 . . . 9.5)

1914.585	58.5	0.77	19.8	360
.646	59.5	0.63	19.0	475
1914.62	59.0	0.70		

Hu. 1640. C. P. D. —52° 12031

R.A. 22^h 22^m 38^s; Decl. —52° 11'.5

(8.6 . . . 12.0)

1914.585	257.5	2.63	20.0	360
.618	257.0	2.70	19.9	360
.687	258.5	2.59	19.9	360
1914.63	257.7	2.64		

Hu. 1641. C.P.D. —63° 4819

R.A. 22^h 39^m 29^s; Decl. —63° 1'.1

(9.0 . . . 10.5)

1914.849	75.7	1.41	2.8	360

Hu. 1642. C.P.D. —52° 12079

R.A. 22^h 44^m 25^s; Decl. —52° 32'.9

(8.5 . . . 11.5)

1914.646	161.0	6.73	20.7	360
.649	160.5	7.27	20.3	360
.684	162.7	6.61	20.2	360
1914.66	161.4	6.87		

Hu. 1643. C.P.D. —59° 7847

R.A. 22^h 53^m 21^s; Decl. —59° 6'.5

(7.0 . . . 10.0)

1914.835	3.9	1.75	2.2	450

Hu. 1644. C.P.D. —62° 6406

R.A. 23^h 5^m 11^s; Decl. —62° 29'.1

(8.8 . . . 9.9)

1914.882	341.8	0.54	3.0	360

Hu. 1645. C.P.D. —61° 6731

R.A. 23^h 5^m 46^s; Decl. —61° 15'.7

(7.5 . . . 9.0)

1914.835	78.9	0.97	2.9	360
.841	77.9	0.91	3.7	360
1914.84	78.4	0.94		

Hu. 1646. C.P.D. —65° 4118

R.A. 23^h 8^m 5^s; Decl. —65° 56'.4

(9.0 . . . 9.0)

1914.882	307.5	0.33	3.4	450

Hu. 1647. C.P.D. —64° 4346

R.A. $23^h\ 15^m\ 53^s$; Decl. —64° 32′.9
(8.8 . . . 11.0)

1914.882	50.6	8.53	3.7	360

Hu. 1648. C.P.D. —63° 4888

R.A. $23^h\ 19^m\ 10^s$; Decl. —63° 55′.7
(7.2 . . . 12.5)

1914.882	282.4	1.93	3.7	360

Hu. 1649. C.P.D. —43° 9803

R.A. $23^h\ 50^m\ 1^s$; Decl. —43° 59′.2
(9.0 . . . . 9.5)

1914.737	265.6	1.04	2.5	360

Hu. 1650. C.P.D. —45° 10495

R.A. $23^h\ 50^m\ 7^s$; Decl. —45° 24′.8
(9.0 . . . 10.0)

1914.737	319.6	4.18	2.7	360

OBSERVATIONS OF SOUTHERN DOUBLE STARS

By W. J. HUSSEY

The following observations of southern double stars were made with the large refractor of the La Plata Observatory during my last two periods of residence in Argentina. The objective of this telescope was made by Paul and Prosper Henry of the Paris Observatory. It has a clear aperture of 433 mm., or 17 inches, and a focal length of 9.6 m. It gives good images for visual work, which is of fundamental importance in the measurement of close pairs. The mounting was made by P. Gautier, of Paris. It is comparatively simple in design, well constructed, and sufficiently rigid for practical purposes. The driving clock has always performed satisfactorily.

Two micrometers have been used in making the measures: a small one originally constructed by P. Gautier for the 8.4-inch refractor of the La Plata Observatory and afterwards modified in the Observatory Shop for use on the large refractor, and a new filar micrometer constructed by The Warner Swasey Company for the large refractor. The small micrometer was used until the new one was received and installed. All the measures since February 11, 1914, have been made with the new micrometer. The telescope and micrometers are briefly described in the first volume of the *Publications* of the La Plata Observatory, to which the reader is referred for further particulars.

In general, each position angle given is derived from the mean of four settings of the circle and each distance is the mean of three measures of the double distance. The numbers in the last two columns are the sidereal times of observation and the powers used. The right ascensions and declinations are for the epoch 1875.0.

ANN ARBOR, MICHIGAN,
MARCH 2, 1915.

h 3391. C.P.D. —58° 42

R.A. $0^h\ 37^m\ 42^s$; Decl. —58° 8′.9
(4.0 . . . 11.0)

1914.852	218°.9	20″.44	$2^h.0$	370

Innes 707. C.P.D. —47° 90

R.A. $0^h\ 44^m\ 1^s$; Decl. —47° 32′.7
(9.3 . . . 10.0)

1913.819	261.8	1.42	....	400
.833	261.1	1.28	2.2	400
1913.83	261.5	1.35		

Innes 49. C.P.D. —53° 228

R.A. $0^h\ 55^m\ 11^s$; Decl. —53° 15′.3
(8.5 . . . 8.5)

1914.684	53.2	0.61	22.7	450

h 3430. C.P.D. —57° 292

R.A. $1^h\ 15^m\ 29^s$; Decl. —57° 59′.9
(7.5 . . . 10.0)

1914.882	236.6	2.43	4.9	450

h 3437. SD. —18° 234

R.A. $1^h\ 21^m\ 59^s$; Decl. —17° 54′.6
(9.0 . . . 9.3)

1912.850	156.8	8.87	23.5	300
.856	157.0	9.09	24.0	300
1912.85	156.9	8.98		

Dunlop 5. C.P.D. —56° 329

R.A. $1^h\ 35^m\ 3^s$; Decl. —56° 49′.7
(7.0 . . . 7.0)

1913.787	205.4	8.55	23.8	300

h 3473. C.P.D. —52° 241

R.A. $1^h\ 51^m\ 7^s$; Decl. —52° 13′.7
(5.0 . . . 10.0)

1914.756	196.6	5.79	23.0	360

Cordoba 4. C.P.D. —52° 246

R.A. $1^h\ 52^m\ 50^s$; Decl. —52° 48′.5
(8.2 . . . 10.0)

1914.756	42.5	3.35	23.3	450

Cordoba 6. C.P.D. —45° 283

R.A. $2^h\ 46^m\ 21^s$; Decl. —45° 45′.4
(9.1 . . . 9.3)

1912.850	2.2	3.29	23.8	300
.859	1.0	3.69	24.0	300
1912.85	1.6	3.49		

h 3550. C.P.D. —51° 361

R.A. $3^h\ 0^m\ 38^s$; Decl. —51° 48′.7
(7.5 . . . 8.0)

1914.756	78.9	38.57	0.7	370

Innes 55. C.P.D. —44° 338

R.A. $3^h\ 8^m\ 2^s$; Decl. —44° 53′.4
(A = 8.0, B = 8.5, C = 11.3)

A B

1912.850	168.5	0.91	0.0	300
.856	167.2	0.83	0.8	300
.859	171.2	0.85	0.1	300
1912.86	169.0	0.86		

AB and C

1912.850	210.4	3.06	0.1	300
.856	206.3	3.23	1.0	300
859	212.4	3.36	0.2	300
1912.86	209.7	3.22		

Innes 56. C.P.D. —43° 353

R.A. $3^h\ 14^m\ 12^s$; Decl. —43° 5′.9
(8.4 . . . 11.3)

1912.853	255.9	3.87	0.4	300
.856	256.3	4.11	1.6	300
.859	255.8	4.04	0.5	300
1912.86	256.0	4.01		

h 3576 = λ 24. C.P.D. —46° 319

R.A. $3^h\ 20^m\ 24^s$; Decl. —46° 6′.3
(7.7 . . . 9.2)

1912.850	342.4	3.23	0.4	300
.853	338.4	3.09	0.9	300
.859	340.0	3.14	0.9	300
1912.85	340.3	3.15		

Cf. Innes: Reference Catalogue, p. 24

h 3575. C.P.D. —51° 404

R.A. $3^h\ 20^m\ 54^s$; Decl. —51° 30′.3
(7.0 . . . 10.0)

1914.756	44.2	28.94	1.0	360

Sellors 5. C.P.D. —48° 391

R.A. $3^h\ 37^m\ 59^s$; Decl. —48° 38′.2
(7.7 . . . 9.2)

1912.894	184.9	1.72	0.8	300
.897	185.0	1.66	0.8	300
1912.90	185.0	1.69		

λ 31. C.P.D. —48° 395

R.A. $3^h\ 42^m\ 28^s$; Decl. —48° 16′.9
(8.5 . . . 12.0)

1912.894	76.4	7.84	1.1	300
.897	74.6	7.32	0.9	300
1912.90	75.5	7.58		

Dunlop 17. C.P.D. —54° 616

R.A. $3^h\ 57^m\ 50^s$; Decl. —54° 40′.4
(7.7 . . . 8.1)

1912.877	195.8	5.39	0.5	300
1913.718	193.1	5.44	1.1	300
.787	194.4	5.49	0.9	300
1913.46	194.4	5.44		

Innes 269. C.P.D. —54° 618

R.A. $3^h\ 58^m\ 2^s$; Decl. —54° 45′.3
(7.7 . . . 11.0)

1912.877	260.9	3.70	0.7	300
1913.787	261.6	3.45	1.0	300
1913.38	261.3	3.58		

Innes 271. C.P.D. —43° 439

R.A. $4^h\ 17^m\ 43^s$; Decl. —43° 5′.1
(7.7 . . . 10.4)

1912.853	142.8	2.69	1.6	300
.856	146.4	3.06	2.3	300
.859	142.2	2.69	1.3	300
1912.86	143.8	2.81		

Rumker 4. C.P.D. —57° 659

R.A. $4^h\ 21^m\ 46^s$; Decl. —57° 21′.2
(7.2 . . . 7.8)

1912.877	239.6	6.40	1.5	300
.951	238.6	6.42	2.4	300
1912.91	239.1	6.41		

Arequipa. C.P.D. —42° 513

R.A. $4^h\ 36^m\ 31^s$; Decl. —42° 6'.2
(4.5 . . . 12.0)

1912.859	115.4	6.69	1.6	300
.916	114.1	6.13	1.6	300
1912.89	114.7	6.36		

Innes 60. C.P.D. —45° 503

R.A. $4^h\ 37^m\ 21^s$; Decl. —45° 56'.8
(8.8 . . . 9.0)

1912.894	96.7	2.79	2.5	300
.897	97.1	2.55	1.8	300
.919	97.0	2.57	2.6	300
1912.90	96.9	2.64		

h 3683. C.P.D. —59° 370

R.A. $4^h\ 38^m 14^s$; Decl. —59° 11'.3
(7.5 . . . 8.0)

1914.920	263.4	0.91	1.6	450

Cordoba 9. C.P.D. —48° 530

R.A. $4^h\ 38^m\ 22^s$; Decl. —48° 3'.8
(7.6 . . . 10.0)

1912.894	234.3	3.78	2.1	300
.897	234.6	4.00	1.7	300
.919	230.3	3.77	2.7	300
1912.90	233.1	3.85		

Innes 342. C.P.D. —54° 718

R.A. $4^h\ 46^m\ 50^s$; Decl. —54° 6'.2
(8.2 . . . 8.6)

1912.935	163.6	1.42	2.5	300
.938	163.4	1.39	2.3	300
1912.94	163.5	1.41		

Innes 343. C.P.D. —54° 719

R.A. $4^h\ 47^m\ 8^s$; Decl. —54° 40'.1
(7.6 . . . 12.0)

1912.877	56.1	2.87	2.0	300
.932	50.5	2.20	2.7	300
.938	49.8	2.59	2.2	300
1912.92	52.1	2.55		

h 3715. C.P.D. —49° 611

R.A. $4^h\ 56^m\ 14^s$; Decl. —49° 38'.7
(7.5 . . . 9.2)

1912.845	112.5	9.87	....	300
.897	112.5	9.78	....	300
1912.87	112.5	9.83		

h 3739. C.P.D. —48° 618

R.A. $5^h\ 10^m\ 6^s$; Decl. —48° 1'.4
(8.4 . . . 9.0)

1912.845	280.0	3.24	....	300
.897	280.8	3.62	....	300
1912.87	280.4	3.43		

h 3767. C.P.D. —47° 595

R.A. $5^h\ 26^m\ 44^s$; Decl. —47° 10'.2
(5.5 . . . 12.0)

1912.845	250.2	25.84	2.3	300
.894	250.0	26.07	3.4	300
.897	250.4	25.86	2.8	300
1912.88	250.2	26.26		

Innes 62. C.P.D. —47° 596

R.A. $5^h\ 27^m\ 7^s$; Decl. —47° 17'.7
(8.9 . . . 9.5)

1912.894	176.8	0.96	3.3	300
.897	180.9	1.03	3.0	300
1912.90	178.9	1.00		

Dunlop 22. C.P.D. —42° 686

R.A. $5^h\ 27^m\ 17^s$; Decl. —42° 23'.7
(6.8 . . . 7.5)

1912.856	168.7	7.44	3.3	300
.859	169.9	7.44	2.4	300
1912.86	169.3	7.44		

h 3784. C.P.D. —46° 609

R.A. $5^h\ 34^m\ 40^s$; Decl. —46° 9'.7
(8.0 . . . 9.3)

1912.845	63.8	5.37	2.5	300
.894	64.1	5.37	3.5	300
.897	63.9	5.51	3.1	300
1912.88	63.9	5.42		

λ 55. C.P.D. —47° 645

R.A. $5^h\ 42^m\ 12^s$; Decl. —47° 25'.9
(8.5 . . . 10.2)

1912.845	308.5	1.27	2.6	300
1913.241	307.9	1.54	8.8	300
.244	308.4	1.44	8.6	300
1913.11	308.3	1.42		

Sellors 15. C.P.D. —61° 541

R.A. 5h 52m 4s; Decl. —61° 51′.7
(7.3 . . . 8.3)

1914.956	319.4	0.62	2.4	450
.961	321.1	0.73	2.5	450
.964	319.5	0.68	4.1	450
1914.96	320.0	0.71		

λ 61. C.P.D. —44° 796

R.A. 6h 4m 54s; Decl. —44° 20′.1
(6.5 . . . 13.0)

1912.916	121.3	33.34	3.0	300
1913.244	120.6	33.46	9.9	240
1913.08	121.0	33.40		

h 3846 = Cape 23. C.P.D. —49° 895

R.A. 6h 11m 10s; Decl. —49° 4′.4
(8.7 . . . 9.8)

1912.845	62.9	4.83	3.1	300
.919	63.2	4.78	3.2	300
1912.88	63.0	4.80		

Innes 3. C.P.D. —61° 607

R.A. 6h 11m 14s; Decl. —61° 26′.2
(7.0 . . . 8.0)

1914.956	4.2	0.75	2.5	450
.961	5.5	0.82	2.6	450
.964	1.3	0.74	4.0	450
1914.96	3.7	0.77		

Innes 156. C.P.D. —48° 856

R.A. 6h 22m 25s; Decl. —48° 6′.3
(6.0 . . . 9.0)

1912.919	129.3	1.06	3.5	450
1913.241	128.7	1.28	9.3	670
.244	127.0	1.28	8.9	670
1913.13	128.3	1.21		

Cordoba. C.P.D. —48° 888

R.A. 6h 32m 33s; Decl. —48° 10′.6
(7.5 . . . 9.2)

1912.845	201.6	10.88	3.6	300
.897	201.5	10.82	3.5	300
.919	202.3	10.88	3.7	300
1912.89	201.8	10.86		

Dunlop 31. C.P.D. —48° 907

R.A. 6h 35m 18s; Decl. —48° 6′.5
(5.5 . . . 8.0)

1912.845	319.4	13.13	3.7	300
.897	319.9	13.00	3.6	300
.919	318.6	13.00	3.8	300
1912.89	319.3	13.04		

Innes 5. C.P.D. —61° 688

R.A. 6h 36m 40s; Decl. —61° 25′.3
(7.0 . . . 8.8)

1914.956	271.1	2.70	3.9	360
.963	271.7	2.76	3.2	360
1914.96	271.4	2.73		

Innes 480. C.P.D. —54° 1088

R.A. 6h 40m 25s; Decl. —54° 59′.5
(7.2 . . . 10.0)

1912.938	2.5	5.81	4.1	300
.951	0.0	5.79	3.0	300
1912.94	1.8	5.80		

Innes 6. C.P.D. —61° 706

R.A. 6h 41m 10s; Decl. —61° 37′.7
(7.5 . . . 8.0)

1914.948	254.2	0.79	3.4	450
.956	253.6	0.75	4.0	450
1914.95	253.9	0.77		

h 3895. C.P.D. —47° 948

R.A. 6h 43m 21s; Decl. —47° 40′.1
(7.0 . . . 10.0)

1912.845	63.5	26.41	3.9	300
.897	64.0	26.43	3.7	300
1912.87	63.8	26.42		

Innes 158. C.P.D. —48° 954

R.A. 6h 44m 3s; Decl. —48° 25′.6
(7.5 . . . 10.5)

1912.919	182.6	1.62	3.9	450
1913.241	185.3	1.81	9.5	670
.244	189.1	1.77	9.0	670
1913.14	185.7	1.73		

Innes 157. C.P.D. —54° 1015

R.A. 6h 44m 10s; Decl. —54° 33′.4
(7.0 . . . 9.5)

1912.938	338.8	1.72	4.3	450

Cape 19. C.P.D. —47° 999

R.A. 6ʰ 48ᵐ 8ˢ; Decl. —47° 36′.0
(9.2 . . . 9.5)

1912.897	300.5	2.04	3.9	300
.919	300.3	2.43	4.0	300
1913.241	301.7	2.43	9.7	670
1913.02	300.8	2.30		

Innes 483. C.P.D. —57° 1116

R.A. 7ʰ 1ᵐ 4ˢ; Decl. —57° 18′.9
(8.8 . . . 11.0)

1912.938	32.9	11.27	4.7	300
.951	33.6	11.34	3.6	300
1913.028	33.6	11.36	4.5	300
1912.97	33.4	11.32		

Hargrave 9. C.P.D. —56° 1265

R.A. 7ʰ 7ᵐ 25ˢ; Decl. —56° 10′.0
(8.3 . . . 9.7)

1912.938	220.4	1.69	4.8	450
.951	224.0	1.30	3.8	450
1913.028	220.4	1.47	4.3	450
1912.97	221.5	1.49		

h 3941. C.P.D. —60° 782

R.A. 7ʰ 7ᵐ 41ˢ; Decl. —60° 10′.6
(8.1 . . . 8.6)

1914.956	302.1	0.93	4.2	360
.964	301.8	0.94	4.9	450
1914.96	302.0	0.94		

Dunlop 41. C.P.D. —55° 1174

R.A. 7ʰ 7ᵐ 51ˢ; Decl. —55° 22′.8
(7.7 . . . 7.7)

1912.938	227.1	7.11	4.4	300
.951	226.1	7.20	4.0	300
1913.028	226.9	7.05	4.2	300
1912.97	226.7	7.12		

Dunlop 41 = Rümker 5 = Ward 3

Sellors 22. C.P.D. —44° 1360

R.A. 7ʰ 10ᵐ 33ˢ; Decl. —44° 26′.7
(9.0 . . . 10.2)

1912.916	261.8	2.16	4.9	450
1913.244	262.6	1.88	11.5	670
1913.08	262.2	2.02		

Innes 7. C.P.D. —46° 1360

R.A. 7ʰ 13ᵐ 54ˢ; Decl. —46° 46′.2
(7.5 . . . 9.2)

1912.919	205.4	0.96	5.1	450
1913.241	210.5	0.88	9.8	670
.244	207.0	0.86	9.1	670
1913.13	207.6	0.90		

Sellors 23. C.P.D. —43° 1376

R.A. 7ʰ 16ᵐ 59ˢ; Decl. —43° 35′.4
(9.0 . . . 10.0)

1912.916	157.7	2.60	5.0	300
1913.020	157.0	2.38	5.5	300
1912.97	157.4	2.49		

λ 88. C.P.D. —56° 1442

R.A. 7ʰ 46ᵐ 26ˢ; Decl. —56° 5′.6
(6.8 . . . 12.2)

1912.938	180.5	6.89	5.4	300
.951	179.8	6.96	4.6	300
1912.94	180.2	6.92		

Cordoba 17. C.P.D. —54° 1401

R.A. 7ʰ 46ᵐ 47ˢ; Decl. —54° 45′.7
(7.5 . . . 9.0)

1912.935	56.5	4.27	5.0	300
.938	55.1	4.00	5.2	300
.951	55.7	4.00	4.3	300
1912.94	55.8	4.09		

Brisbane. C.P.D. —44° 2475

R.A. 8ʰ 14ᵐ 48ˢ; Decl. —44° 38′.7
(8.0 . . . 8.2)

1913.017	326.9	5.29	5.8	300
.028	327.7	5.42	5.4	300
.034	326.7	5.24	4.9	300
1913.03	327.1	5.32		

Dunlop 70. C.P.D. —44° 2668

R.A. 8ʰ 25ᵐ 15ˢ; Decl. —44° 18′.3
(6.2 . . . 8.0)

1912.916	352.3	4.87	5.6	300
1913.017	350.0	4.80	6.4	300
.028	352.9	4.73	5.7	300
1912.99	351.7	4.80		

Innes 168. C.P.D. —44° 2685

R.A. 8h 26m 26s; Decl. —44° 18′.9

(7.0 . . . 10.5)

1913.017	76.6	3.53	6.5	300
.028	80.3	3.70	5.8	300
.034	73.4	3.58	5.5	300
.036	74.8	3.63	6.7	300
.088	74.9	3.55	5.2	300
1913.04	76.0	3.60		

Innes 315 = Innes 811. C.P.D. —42° 2827

R.A. 8h 37m 28s; Decl. —42° 9′3

(9.3 . . . 9.7)

1913.017	168.5	0.90	7.0	450
.028	173.3	0.90	6.4	450
.034	175.0	1.08	6.5	450
.088	169.7	1.03	5.7	450
1913.04	171.6	0.98		

Jacob 5. C.P.D. —42° 2926

R.A. 8h 42m 4s; Decl. —42° 6′.5

(8.0 . . . 9.5)

1913.028	310.0	2.28	6.5	300
.034	309.9	2.31	6.7	300
.088	309.6	2.50	5.8	300
1913.05	309.8	2.36		

Innes 317. C.P.D. —42° 3114

R.A. 8h 50m 40s; Decl. —42° 59′.4

(8.2 . . . 9.0)

1913.020	302.0	2.21	6.0	300
.028	304.8	2.25	6.7	300
.036	303.0	2.15	6.6	300
1913.03	303.3	2.20		

Cordoba 20. C.P.D. —42° 3149

R.A. 8h 52m 36s; Decl. —42° 46′.4

(7.7 . . . 9.5)

1913.020	49.9	3.26	6.1	300
.036	48.4	3.13	6.7	300
.088	48.4	3.29	6.2	300
1913.05	48.9	3.23		

h 4181. C.P.D. —54° 2020

R.A. 9h 2m 29s; Decl. —54° 13′.8

(9.5 . . . 9.8)

1913.151	134.8	3.21	7.8	300
.157	133.3	2.91	6.6	300
1913.15	134.0	3.06		

Cordoba 21. C.P.D. —43° 3403

R.A. 9h 5m 22s; Decl. —43° 40′.0

(8.0 . . . 9.0)

1912.916	49.4	2.69	6.9	300
1913.020	47.4	2.43	6.6	300
.036	50.6	2.75	7.0	300
.088	48.3	2.99	6.6	300
1913.02	48.9	2.72		

λ 110. C.P.D. —46° 3477

R.A. 9h 7m 18s; Decl. —46° 22′.3

(9.0 . . . 9.0)

1913.020	53.8	1.15	6.8	300

Innes 11. C.P.D. —45° 3566

R.A. 9h 10m 43s; Decl. —45° 2′.3

(6.5 . . . 7.0)

1913.020	280.4	0.95	7.1	450
.195	274.4	0.78	7.3	670
1913.11	277.4	0.87		

Innes 31. C.P.D. —56° 2266

R.A. 9h 27m 7s; Decl. —56° 25′.9

(9.0 . . . 10.0)

1913.122	155.5	3.24	7.0	300
.144	155.4	3.20	7.6	300
1913.13	155.5	3.22		

Innes 836. C.P.D. —54° 2510

R.A. 9h 33m 32s; Decl. —54° 22′.6

(8.8 . . . 11.0)

1913.122	203.1	2.50	6.8	300
.144	205.1	2.53	7.8	300
.151	201.8	2.55	8.2	300
1913.14	203.3	2.53		

Dunlop 81. C.P.D. —44° 4340

R.A. 9h 49m 22s; Decl. —44° 41′.6

(6.0 . . . 8.5)

1913.020	240.9	5.39	7.6	300
.034	240.5	5.69	7.1	300
.036	241.9	5.46	7.3	300
1913.03	241.1	5.51		

Innes 499. C.P.D. —53° 3290

R.A. 10h 1m 25s; Decl. —53° 59′.2

(8.0 . . . 10.0)

1913.110	305.3	2.15	7.6	300
.122	306.1	1.76	8.0	300
.144	302.7	1.91	8.2	300
1913.12	304.7	1.94		

λ 118 = Innes 850. C.P.D. —54° 3352

R.A. 10ʰ 10ᵐ 33ˢ; Decl. —54° 55′.8
(7.5 . . . 12.5)

1913.122	145.3	14.03	7.6	300

Russell 140. C.P.D. —55° 3229

R.A. 10ʰ 14ᵐ 26ˢ; Decl. —55° 23′.7
(8.0 . . . 9.0)

1913.107	279.6	3.67	7.6	300
.122	281.3	3.41	8.2	300
.144	278.9	3.60	8.3	300
1913.12	279.9	3.56		

Innes 208. C.P.D. —43° 4636

R.A. 10ʰ 18ᵐ 31ˢ; Decl. —43° 36′.6
(7.5 . . . 8.5)

1913.036	29.5	0.84	8.4	450

Dunlop 88. C.P.D. —44° 4896

R.A. 10ʰ 26ᵐ 37ˢ; Decl. —44° 25′.4
(6.0 . . . 6.3)

1913.020	218.4	13.39	8.6	300
.034	218.9	13.55	8.0	300
.036	218.5	13.47	6.0	300
1913.03	218.6	13.47		

Cordoba 24. C.P.D. —57° 3472

R.A. 10ʰ 30ᵐ 18ˢ; Decl. —57° 1′.9
(8.0 . . . 10.5)

1913.187	239.7	4.93	7.4	670
.297	239.2	5.14	14.2	670
1913.24	239.5	5.04		

Cordoba 25. C.P.D. —44° 5033

R.A. 10ʰ 37ᵐ 6ˢ; Decl. —44° 36′.4
(8.8 . . . 9.5)

1913.034	225.3	3.18	8.1	300
.036	225.9	3.06	8.5	300
.195	226.1	2.80	8.6	300
1913.09	225.8	3.01		

Innes 398. C.P.D. —56° 3761

R.A. 10ʰ 40ᵐ 46ˢ; Decl. —56° 39′.6
(9.2 . . . 9.5)

1913.187	234.6	4.60	8.0	300
.297	235.4	4.87	14.4	300
1913.24	235.0	4.74		

Innes 862. C.P.D. —54° 4128

R.A. 10ʰ 48ᵐ 30ˢ; Decl. —54° 36′.4
(8.8 . . . 9.5)

1913.107	10.2	2.38	8.1	300
.110	10.9	2.43	8.1	300
.122	10.5	2.47	8.6	300
1913.11	10.5	2.43		

Innes 863. C.P.D. —54° 4208

R.A. 10ʰ 53ᵐ 22ˢ; Decl. —54° 16.2
(9.0 . . . 9.2)

1913.107	318.4	1.37	8.2	300
.110	316.8	1.23	8.2	300
1913.11	317.6	1.30		

Innes 865. C.P.D. —48° 3648

R.A. 10ʰ 55ᵐ 0ˢ; Decl. —48° 39′.9
(8.5 . . . 10.0)

1913.487	288.1	2.57	14.4	300

Innes 875. C.P.D. —54° 4427

R.A. 11ʰ 11ᵐ 0ˢ; Decl. —54° 52′.5
(8.5 . . . 10.5)

1913.107	239.0	2.23	8.7	300
.151	235.3	2.47	9.4	300
1913.13	237.2	2.35		

λ 129. C.P.D. —52° 4466

R.A. 11ʰ 14ᵐ 8ˢ; Decl. —52° 47′.5
(7.6 . . . 11.8)

1914.967	7.1	6.68	8.4	360
.972	6.8	6.77	8.7	360
1914.97	7.0	6.73		

Russell 168. C.P.D. —42° 5254

R.A. 11ʰ 16ᵐ 32ˢ; Decl. —42° 16′.4
(9.0 . . . 9.5)

1913.020	307.6	3.20	8.9	300
.195	308.2	2.97	8.9	300
1913.11	307.9	3.09		

Gillis 165 = W. O. 112. C.P.D. —60° 3159

R.A. 11ʰ 30ᵐ 43ˢ; Decl. —60° 12′.1
(7.5 . . . 8.5)

1914.961	4.6	2.01	....	450
.964	5.7	1.92	8.4	360
1914.96	5.2	1.97		

Innes 890. C.P.D. — 54° 4744

R.A. $11^h\ 38^m\ 47^s$; Decl. — 54° 46′.1
(8.2 . . . 11.2)

1913.157	306.2	2.53	9.3	300
.184	309.3	2.59	9.6	300
.187	306.6	2.84	9.3	300
1913.18	307.4	2.65		

Cordoba. C.P.D. — 25° 4812

R.A. $11^h\ 39^m\ 2^s$; Decl. — 25° 32′.5
(8.5 . . . 9.0)

1913.277	275.2	4.88	9.8	300

Russell 179. C.P.D. — 57° 4970

R.A. $11^h\ 39^m\ 58^s$; Decl. — 57° 23′.5
(8.8 . . . 8.8)

1913.157	177.6	5.20	9.6	300
.184	177.3	5.05	9.8	300
.187	177.1	5.27	9.8	300
1913.18	177.3	5.17		

Innes 894. C.P.D. — 44° 5764

R.A. $11^h\ 51^m\ 26^s$; Decl. — 44° 38′.6
(9.2 . . . 9.6)

1913.238	197.8	1.25	9.4	300
.241	200.4	1.35	9.3	670
.487	200.7	1.20	15.1	300
1913.32	200.0	1.27		

W. O. 115. C.P.D. — 57° 5217

R.A. $11^h\ 57^m\ 22^s$; Decl. — 57° 2′.8
(8.2 . . . 9.5)

1913.107	245.2	1.86	10.0	300
.144	245.9	1.98	9.6	300
.151	244.4	2.06	9.7	300
1913.13	245.2	1.97		

Innes 423. C.P.D. — 44° 5866

R.A. $12^h\ 4^m\ 33^s$; Decl. — 44° 43′.7
(7.0 . . . 12.2)

1913.238	164.1	2.91	9.6	300
.241	163.9	2.92	9.5	300
1913.24	164.0	2.92		

Howe 20. C.P.D. — 23° 5474

R.A. $12^h\ 15^m\ 2^s$; Decl. — 23° 31′.6
(8.5 . . . 8.8)

1913.258	149.6	5.20	9.8	300
.277	148.6	5.26	10.4	300
1913.27	149.1	5.23		

Innes 903. C.P.D. — 43° 5774

R.A. $12^h\ 16^m\ 54^s$; Decl. — 43° 59′.9
(9.5 . . . 10.5)

1913.261	271.6	2.69	9.9	240

α Crucis. C.P.D. — 62° 2745

R.A. $12^h\ 19^m\ 38^s$; Decl. — 62° 24′.3
(3.0 . . . 3.5)

1914.964	118.1	5.14	9.2	360

Innes 219. C.P.D. — 55° 5115

R.A. $12^h\ 24^m\ 55^s$; Decl. — 55° 25′.7
(8.8 . . . 9.5)

1913.110	51.7	1.79	9.3	300
.122	55.6	1.67	9.5	300
.144	51.2	2.13	10.0	300
.151	49.4	2.13	10.1	300
1913.13	52.0	1.93		

W. O. 116. C.P.D. — 55° 5161

R.A. $12^h\ 31^m\ 7^s$; Decl. — 55° 14′.5
(7.2 . . . 8.8)

1913.116	194.0	1.91	9.6	300
.122	193.1	1.99	9.6	300
.144	192.9	1.94	10.3	300
1913.12	193.3	1.95		

Innes 908. C.P.D. — 24° 4902

R.A. $12^h\ 36^m\ 50^s$; Decl. — 24° 33′.2
(9.5 . . . 10.5)

1913.258	155.7	3.43	10.0	300
.277	153.7	3.46	10.5	300
1913.27	154.7	3.45		

N. Z. 31. C.P.D. — 45° 6031

R.A. $12^h\ 39^m\ 26^s$; Decl. — 45° 23′.4
(9.5 . . . 10.0)

1913.261	23.3	1.37	10.3	300

Cin. 74. C.P.D. — 23° 5710

R.A. $13^h\ 7^m\ 42^s$; Decl. — 23° 37′.3
(6.5 . . . 11.0)

1913.277	333.0	12.44	11.4	300

Innes 920. C.P.D. — 22° 5583

R.A. $13^h\ 11^m\ 16^s$; Decl. — 22° 50′.4
(8.5 . . . 11.2)

1913.258	222.8	1.32	10.7	300
.277	217.3	1.45	11.6	300
1913.27	220.0	1.39		

Innes 939. C.P.D. —44° 6627

R.A. $13^h\ 56^m\ 16^s$; Decl. —44° 0'.8
(A = 8.8, B = 8.8, C = 12.0)

A B

1913.261	144.2	0.76	11.3	670
.294	136.4	0.78	10.6	670
1913.28	140.3	0.77		

A B and C

1913.294	74.0	7.94	10.7	300

Innes 522 = Innes 940. C.P.D. —23° 5832

R.A. $13^h\ 56^m\ 44^s$; Decl. —23° 32'.6
(8.4 . . . 9.0)

1913.258	296.0	1.05	12.0	670
.277	299.6	0.83	11.8	670
1913.27	297.8	0.94		

λ 198 = Innes 942. C.P.D. —43° 6429

R.A. $14^h\ 2^m\ 8^s$; Decl. —43° 41'.2
(7.6 . . . 11.8)

1913.294	139.1	9.29	11.2	300
.624	135.8	8.67	18.1	300
1913.46	137.4	8.98		

Innes 943. C.P.D. —44° 6671

R.A. $14^h\ 2^m\ 45^s$; Decl. —44° 24'.9
(8.9 . . . 11.5)

1913.261	315.0	4.61	11.7	300
.294	316.2	4.60	11.1	300
1913.28	315.6	4.61		

Innes 402. C.P.D. —44° 6770

R.A. $14^h\ 18^m\ 10^s$; Decl. —44° 48'.8
(4.9)

1913.294. Appears round with power 670

Innes 958. C.P.D. —24° 5466

R.A. $15^h\ 4^m\ 30^s$; Decl. —24° 9'.8
(9.5 . . . 9.8)

1913.277	100.2	0.74	13.2	670

Sh 228. C.P.D. —23° 6369

R.A. $16^h\ 18^m\ 5^s$; Decl. —23° 9'.4
(4.5 . . . 6.0)

1913.277	171.2	3.60	13.8	670

Antares.

R.A. $16^h\ 21^m\ 45^s$; Decl. —26° 9'.1
(1.0 . . . 8.0)

1913.439	270.6	3.24	15.3	300

Innes 995. C.P.D. —45° 8203

R.A. $16^h\ 46^m\ 27^s$; Decl. —45° 7'.6
(8.0 . . . 11.5)

1913.258	227.4	2.16	13.9	300
.294	230.4	2.43	13.4	300
.441	231.8	1.98	14.0	300
.709	231.3	....	20.3	300
1913.42	230.2	2.19		

W. O. 131. C.P.D. —56° 7940

R.A. $16^h\ 50^m\ 42^s$; Decl. —56° 21'.6
(7.0 . . . 9.0)

1914.695	128.2	2.06	21.2	450
.698	130.0	2.26	20.2	360
1914.70	129.1	2.16		

Innes 102. C.P.D. —44° 8242

R.A. $16^h\ 58^m\ 20^s$; Decl. —44° 16'.2
(7.5 . . . 10.0)

1913.709	138.1	4.93	20.7	300

Arequipa. C.P.D. —44° 8358

R.A. $17^h\ 10^m\ 21^s$; Decl. —44° 5'.2
(8.0 . . . 8.0)

1913.441	10.7	0.54	14.3	670

λ 328. C.P.D. —50° 10093

R.A. $17^h\ 17^m\ 31^s$; Decl. —50° 32'.1
(11.0 . . . 12.0)

1914.698	275.9	4.30	20.7	360

Innes 40. C.P.D. —45° 8654

R.A. $17^h\ 22^m\ 33^s$; Decl. —45° 56'.2
(6.0 . . . 10.0)

1913.709	209.9	18.03	21.5	300

Innes 603. C.P.D. —45° 8680

R.A. $17^h\ 24^m\ 43^s$; Decl. —45° 32'.0
(8.5 . . . 10.0)

1913.709	83.7	1.59	21.7	300

Pollock 4. C.P.D. —53° 8731

R.A. $17^h\ 31^m\ 22^s$; Decl. —53° 24'.0
(8.0 . . . 10.5)

1914.698	296.1	11.00	21.4	360

Hargrave 124. C.P.D. —52° 10777

R.A. $17^h\ 32^m\ 2^s$; Decl. —52° 43'.6
(9.0 . . . 10.0)

1914.698	125.5	5.11	21.2	360

h 4978. C.P.D. —53° 8799

R.A. $17^h\ 40^m\ 18^s$; Decl. —53° 34'.1
(6.5 . . . 10.5)

1914.698	268.0	12.40	21.7	360

h 4984. C.P.D. — 52° 10900

R.A. $17^h\ 42^m\ 40^s$; Decl. — 52° 26′.5

(8.0 . . . 10.5)

1914.698	9.5	12.47	21.8	360

h 4994. C.P.D. — 52° 10927

R.A. $17^h\ 47^m\ 16^s$; Decl. — 52° 10′.8

(9.0 . . . 9.5)

1914.698	210.2	14.09	22.0	360

h 5014. C.P.D. —43° 8434

R.A. $17^h\ 57^m\ 47^s$; Decl. — 43° 25′.6

(6.0 . . . 6.2)

1913.441	57.8	0.96	14.7	670
.710	55.2	1.27	22.5	300
1913.58	56.5	1.11		

Cordoba 51. C.P.D. — 42° 8379

R.A. $18^h\ 14^m\ 21^s$; Decl. — 42° 50′.1

(8.6 . . . 9.0)

1913.441	136.5	3.45	15.0	300
.710	135.8	3.36	22.7	300
1913.68	136.2	3.41		

Innes 250. C.P.D. — 42° 8453

R.A. $18^h\ 32^m\ 20^s$; Decl. — 42° 16′.6

(7.5 . . . 8.5)

1913.439	130.0	0.73	16.5	670
.441	130.3	0.69	15.3	670
.710	129.1	1.12	23.3	300
1913.53	129.8	0.85		

Pollock 7 = λ 366. C.P.D. — 42° 8570

R.A. $18^h\ 53^m\ 49^s$; Decl. — 42° 26′.4

(9.0 . . . 9.2)

1913.710	182.6	2.30	23.5	300
.792	182.5	2.38	23.0	300
1913.75	182.6	2.34		

λ 365. C.P.D. — 42° 8577

R.A. $18^h\ 54^m\ 29^s$; Decl. — 42° 48′.7

(9.2 . . . 9.5)

1913.710	79.2	4.44	23.6	300
.792	77.7	4.36	23.1	300
1913.75	78.5	4.40		

Dunlop 225. C.P.D. — 52° 11383

R.A. $19^h\ 2^m\ 36^s$; Decl. — 52° 0′.4

(A = 7.6, B = 8.2, C = 10.8)

	A B			
1914.698	71.9	70.52	22.1	360
	A C			
1914.698	79.7	29.66	22.2	360

Innes 643. C.P.D. — 56° 9135

R.A. $19^h\ 6^m\ 31^s$; Decl. — 56° 9′.0

(9.0 . . . 9.3)

1914.695	47.4	1.19	21.5	360

h 5104. C.P.D. — 51° 10202-3

R.A. $19^h\ 11^m\ 15^s$; Decl. — 51° 16′.8

(9.0 . . . 9.0)

1914.698	38.9	18.46	22.5	360

Innes 649. C.P.D. — 51° 11230

R.A. $19^h\ 15^m\ 25^s$; Decl. — 51° 40′.1

(9.0 . . . 10.0)

1914.698	274.9	2.06	22.7	360

Innes 120 and h 5141. C.P.D. — 62° 6108

R.A. $19^h\ 38^m\ 0^s$; Decl. — 62° 7′.0

(A = 7.5, B = 7.5, C = 10.4)

	A B			
1914.849	135.5	0.40	0.5	450
.852	132.5	0.45	0.0	450
1914.85	134.0	0.42		
	A B and C			
1914.849	342.6	19.69	0.6	360
.852	342.1	19.44	23.8	360
1914.85	342.4	19.57		

h 5140. C.P.D. — 65° 3825

R.A. $19^h\ 38^m\ 2^s$; Decl. — 65° 12′.9

(8.2 . . . 8.4)

1914.849	85.6	1.89	23.9	450
.852	84.3	1.99	23.7	360
1914.85	85.0	1.94		

Innes 122. C.P.D. — 42° 8921

R.A. $19^h\ 42^m\ 1^s$; Decl. — 42° 10′.2

(8.0 . . . 11.0)

1913.710	338.0	5.98	0.3	300
.792	337.5	5.37	0.1	300
1913.75	337.8	5.67		

h 5163. C.P.D. — 63° 4561

R.A. $19^h\ 53^m\ 57^s$; Decl. — 63° 24′.4

(7.6 . . . 8.0)

1914.852	252.5	1.72	0.4	360
.871	250.1	1.55	0.3	360
.873	251.9	1.67	0.3	360
1914.86	251.5	1.65		

h 5167. C.P.D. —63° 4566

R.A. $20^h\ 0^m\ 37^s$; Decl. $-63°\ 58'.9$
(7.2 . . . 9.0)

1914.849	34.0	7.34	1.4	360
.852	35.2	7.24	0.8	360
.871	35.4	7.23	0.2	360
.873	35.8	7.15	0.1	360
1914.86	35.1	7.24		

h 5171. C.P.D. —64° 4035

R.A. $20^h\ 3^m\ 12^s$; Decl. $-64°\ 48'.0$
(A = 6.8, B = 9.8, C = 9.5)

	A B			
1914.871	305.4	17.65	0.6	360
	A C			
1914.871	335.6	30.07	0.5	360

Innes 411. C.P.D. —62° 6150

R.A. $20^h\ 5^m\ 13^s$; Decl. $-62°\ 32'.4$
(8.4 . . . 9.1)

1914.849	290.6	0.75	1.2	360
.852	283.2	1.13	0.9	360
1914.85	286.8	0.94		

h 5185. C.P.D. —59° 7604

R.A. $20^h\ 10^m\ 23^s$; Decl. $-59°\ 7'.0$
(7.8 . . . 11.0)

1914.841	61.3	18.89	0.9	360
.844	60.7	18.70	23.3	360
.847	60.7	18.77	0.2	360
1914.84	60.9	18.79		

β 763. C.P.D. —42° 9065

R.A. $20^h\ 13^m\ 59^s$; Decl. $-42°\ 26'.5$
(6.0 . . . 7.0)

1912.705	228.0	....	....	670
1913.439	227.4	1.05	17.2	300
.710	226.7	1.08	0.7	300
.792	227.5	0.88	0.3	400
.819	224.7	0.98	23.9	400
1913.49	227.1	1.00		

h 5204. C.P.D. —45° 9966

R.A. $20^h\ 23^m\ 30^s$; Decl. $-45°\ 46'.3$
(7.8 . . . 8.5)

1912.705	35.2	6.03	....	300
1913.439	34.5	6.45	17.3	300
.710	34.2	6.45	1.1	300
1913.28	35.0	6.31		

Innes 41. C.P.D. —45° 9989

R.A. $20^h\ 27^m\ 51^s$; Decl. $-45°\ 59'.3$
(7.0 . . . 8.0)

1913.439	357.8	1.76	17.5	670
.710	360.0	1.77	1.1	300
.792	357.0	1.66	0.7	300
.819	359.6	1.91	0.5	400
1913.69	358.6	1.77		

Russell 323. C.P.D. —63° 4604

R.A. $20^h\ 30^m\ 32^s$; Decl. $-63°\ 8'.0$
(8.8 . . . 10.5)

1914.912	315.3	3.02	0.8	360

Rumker 26. C.P.D. —62° 6180

R.A. $20^h\ 41^m\ 11^s$; Decl. $-62°\ 53'.5$
(6.0 . . . 6.5)

1914.852	93.0	2.58	1.5	450
.873	93.7	2.81	1.2	360
.912	93.3	2.78	0.9	360
1914.88	93.3	2.72		

Innes 18. C.P.D. —52° 11793

R.A. $20^h\ 46^m\ 3^s$; Decl. $-52°\ 35'.1$
(6.8 . . . 10.5)

1914.646	2.7	4.38	18.2	475
.649	2.7	4.05	18.3	360
.858	0.3	4.27	1.5	360
1914.73	1.9	4.23		

Innes 129. C.P.D. —59° 7652

R.A. $20^h\ 46^m\ 34^s$; Decl. $-59°\ 44'.6$
(8.5 . . . 10.0)

1914.841	7.9	2.02	1.8	360
.844	7.3	1.84	0.3	450
1914.84	7.6	1.93		

h 5302. C.P.D. —53° 10200

R.A. $21^h\ 48^m\ 6^s$; Decl. $-53°\ 38'.3$
(8.7 . . . 10.5)

1914.618	351.5	12.57	18.9	360

h 5309. C.P.D. —51° 11755

R.A. $21^h\ 48^m\ 58^s$; Decl. $-51°\ 39'.6$
(9.5 . . . 9.8)

1914.618	348.1	9.13	19.2	360
.640	348.0	9.06	19.1	360
1914.63	348.1	9.10		

Innes 669. C.P.D. —52° 11799

R.A. $20^h\ 50^m\ 38^s$; Decl. $-52°\ 39'.0$
(8.5 . . . 8.5)

1914.646	72.8	0.71	18.3	450

Innes 130. C.P.D. —48° 10519

R.A. 20h 55m 31s; Decl. —48° 27′.2
(7.0 . . . 11.5)

1913.819	316.3	3.38	1.2	400
.833	317.4	3.19	0.2	400
1913.83	316.9	3.28		

h 5250. C.P.D. —64° 4110

R.A. 21h 5m 5s; Decl. —64° 12′.1
(8.0 . . . 10.0)

1914.912	305.3	9.65	1.3	360

Russell 329. C.P.D. —60° 7461

R.A. 21h 9m 19s; Decl. —60° 44′.0
(9.5 . . . 10.0)

1914.844	298.7	21.48	1.1	360

h 5256. C.P.D. —60° 7464-5

R.A. 21h 10m 22s; Decl. —60° 49′.1
(8.8 . . . 8.9)

1914.844	152.1	27.13	1.3	360

Innes 126. C.P.D. —57° 9665

R.A. 21h 13m 18s; Decl. —57° 30′.2
(9.5 . . . 9.8)

1913.828	78.3	1.69	1.1	400
.836	80.4	1.88	0.1	400
1913.83	79.4	1.79		

Innes 132. C.P.D. —52° 11862

R.A. 21h 14m 20s; Decl. —52° 28′.2
(7.5 . . . 10.0)

1914.585	292.2	1.51	18.5	360
.646	291.0	1.46	18.4	475
1914.62	291.6	1.48		

Russell 332. Not in C.P.D.

R.A. 21h 20m 25s±; Decl. —60° 48′±
(10.5 . . . 11.5)

1914.844	333.9	14.01	1.8	360
.847	333.7	13.57	0.7	360
1914.85	333.8	13.79		

h 5270. C.P.D. —60° 7481

R.A. 21h 20m 56s; Decl. —60° 45′.0
(7.8 . . . 11.2)

1914.844	54.9	27.42	1.7	360
.847	54.4	27.32	0.5	360
1914.85	54.7	27.37		

h 5286. C.P.D. —58° 7886

R.A. 21h 34m 29s; Decl. —58° 27′.9
(8.4 . . . 10.0)

1914.847	87.8	8.21	1.2	360

Arequipa. C.P.D. —62° 6277

R.A. 21h 45m 57s; Decl. —62° 28′.2
(6.9)

1914.920. Examined this star under favorable conditions with powers 360, 450, and 670. It appears perfectly round with all powers. Also examined the neighboring stars of magnitudes 7.3 and 7.4. They also appeared single.

Innes 381. C.P.D. —57° 10027

R.A. 21h 57m 28s; Decl. —57° 4′.6
(8.5 . . . 10.0)

1913.831	109.4	1.67	2.9	400

h 5316. C.P.D. —59° 7765

R.A. 21h 58m 18s; Decl. —59° 44′.1
(8.6 . . . 9.0)

1914.838	140.0	3.89	2.5	360
.841	139.2	3.73	2.7	360
.847	140.8	3.86	1.7	360
1914.84	140.0	3.83		

h 5317. C.P.D. —59° 7773

R.A. 22h 3m 6s; Decl. —59° 26′.6
(8.8 . . . 9.3)

1914.841	99.3	14.59	2.8	360
.847	100.6	14.45	1.9	360
1914.84	100.0	14.52		

Innes 20. C.P.D. —63° 4769

R.A. 22h 9m 10s; Decl. —63° 25′.9
(7.2 . . . 8.0)

1914.852	329.2	0.42	2.5	450
.873	330.2	0.53	2.7	450
.920	324.9	0.31	2.7	670
1914.88	328.1	0.42		

h 5323. C.P.D. —61° 6640

R.A. 22h 10m 51s; Decl. —61° 25′.1
(8.5 . . . 8.7)

1914.841	204.0	26.44	3.0	360
.847	204.6	26.50	2.4	360
1914.84	204.3	26.47		

h 5327. C.P.D. —65° 4027

R.A. 22h 14m 4s; Decl. —65° 46'.8
(9.5 . . . 10.5)

1914.912	128.8	25.71	2.4	360

Innes 383. C.P.D. —58° 7954

R.A. 22h 16m 37s; Decl. —58° 25'.1
(6.0 . . . 12.0)

1914.847	237.1	81.15	2.7	360

h 5334. C.P.D. —65° 4044

R.A. 22h 18m 25s; Decl. —65° 36'.0
(5.0 . . . 9.0)

1914.852	282.4	7.10	3.0	360
.873	282.3	7.24	2.9	360
1914.86	282.4	7.17		

h 5338. C.P.D. —52° 12028

R.A. 22h 20m 39s; Decl. —52° 25'.4
(7.5 . . . 11.0)

1914.618	182.5	30.58	19.5	360
.640	182.6	30.13	19.5	360
.649	182.0	30.47	19.3	360
1914.64	182.4	30.39		

h 5348. C.P.D. —59° 7821

R.A. 22h 31m 2s; Decl. —59° 27'.4
(7.3 . . . 9.5)

1914.841	274.3	4.33	3.3	360

h 5349. C.P.D. —53° 10326

R.A. 22h 31m 24s; Decl. —53° 20'.4
(6.5 . . . 11.5)

1914.635	117.3	34.18	19.9	360
.646	118.5	33.44	19.3	360
.687	118.5	34.74	20.1	360
1914.66	118.1	34.12		

h 5354. C.P.D. —58° 7981

R.A. 22h 32m 29s; Decl. —58° 29'.4
(8.8 . . . 9.0)

1914.841	75.6	21.46	3.2	360

Cordoba 64. C.P.D. —46° 10486

R.A. 22h 56m 49s; Decl. —46° 50'.4
(8.0 . . . 9.0)

1913.833	108.9	3.63	1.5	300

Dunlop 246. C.P.D. —51° 11908

R.A. 23h 0m 1s; Decl. —51° 21'.6
(6.5 . . . 7.5)

1914.618	258.1	8.68	20.2	360
.858	257.8	8.36	3.1	360
1914.74	258.0	8.52		

Dunlop 245 = Gillis 282. C.P.D. —60° 7635

R.A. 23h 1m 2s; Decl. —60° 24'.5
(7.3 . . . 9.5)

1914.841	291.3	13.99	3.5	360

h 5392 = Russell 343. C.P.D. —58° 8064

R.A. 23h 11m 16s; Decl. —58° 59'.0
(7.8 . . . 9.0)

1914.841	327.8	24.18	3.9	360

The angle given by Herschel is 17° and that of Russell 338°, from which it appears that there is a comparatively rapid change in angle, probably due to proper motion.

Dunlop 248. C.P.D. —50° 11799

R.A. 23h 13m 48s; Decl. —50° 59'.3
(6.0 . . . 7.0)

1914.618	211.2	16.77	20.8	360

Dunlop 250. C.P.D. —50° 11819

R.A. 23h 20m 13s; Decl. —50° 58'.1
(6.5 . . . 8.5)

1914.618	88.9	39.33	21.2	360

h 5425. C.P.D. —61° 6769

R.A. 23h 43m 38s; Decl. —61° 47'.9
(10.0 . . . 11.0)

1914.841	175.3	13.81	4.8	360

Sellors 14. C.P.D. —52° 12220

R.A. 23h 43m 58s; Decl. —52° 23'.8
(8.0 . . . 8.5)

1914.646	26.8	1.03	21.2	670

Cordoba 69. C.P.D. —48° 11009

R.A. 23h 57m 33s; Decl. —48° 49'.4
(7.5 . . . 10.2)

1913.710	67.9	3.50	21.4	300
.819	65.9	3.33	4.3	400
1913.71	66.9	3.42		

Arequipa. C.P.D. —49° 11858

R.A. 23h 59m 51s; Decl. —49° 46'.3
(5.8 . . . 10.5)

1914.767	174.6	5.49	22.2	360

OBSERVATIONS OF COMETS AND MINOR PLANETS

The observations given below of comets and minor planets having Ann Arbor mean time were made with the 12¼-inch refractor of the Observatory of the University of Michigan, and those having La Plata mean times were made with the 17-inch refractor of the Observatory of the National University of La Plata.

The filar micrometer used at Ann Arbor was made in 1907 by The Warner & Swasey Company for the 12¼-inch refractor. It is described in these Publications, Vol. I, page 13. The filar micrometer used at La Plata was made by P. Gautier, of Paris, for the 8.4-inch refractor of the La Plata Observatory, and remodeled in the Instrument Shop of that Observatory for temporary use on the 17-inch refractor. It is described in the first volume of the Publications of the La Plata Observatory.

Whenever the comparison stars were near enough the observations were made by direct micrometer measurements. Only a few of the observations were made by the method of transits.

A few of the observations made at Ann Arbor were reduced by Mr. Frank D. Urie, now of the Elgin Observatory, while he was an Assistant in the Observatory of the University of Michigan. All of the observations made at La Plata were reduced by Mr. B. H. Dawson, Astronomer in the Observatory of La Plata.

OBSERVATIONS OF COMET DANIEL, 1909 *a*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1909 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	LOG $p\Delta$ FOR δ
June 17	$13^h 21^m 1^s$	1	15, 10	$-2^m 19^s.52$	$+0' 54''.0$	$1^h 45^m 24^s.70$	$+31° 46' 29''.5$	9.7038n	0.7494
18	13 34 7	2	12, 8	−1 20.03	−6 31.4	1 48 17.67	+33 11 16.5	9.7126n	0.7302
19	13 35 37	3	8, 8	+0 24.83	+0 18.2	1 51 14.51	+34 33 27.0	9.7201n	0.7194
20	14 7 12	4	8, 8	−0 36.46	+5 49.2	1 54 19.45	+35 55 36.1	9.7296n	0.6655
July 16	13 46 40	5	10, 8	−0 9.55	+3 17.7	3 37 47.06	+60 3 39.6	9.9400n	0.5127
23	13 52 52	6	8, 8	−0 48.89	+6 24.8	4 12 30.74	+63 43 7.2	9.9912n	0.4724

BY GEO. A. LINDSAY.

1909 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	LOG $p\Delta$ FOR δ
July 16	$14^h 14^m 5^s$	4	8, 8	$-0^m 5^s.06$	$+4' 7''.3$	$3^h 37^m 42^s.00$	$+60° 7' 46''.9$	9.9194n	0.4944
23	14 21 44	6	8, 8	−0 42.07	+6 54.5	4 12 37.56	+63 43 36.9	9.9905n	0.3532

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	$1^h 47^m 44^s.66$	$-0^s.44$	$+31° 45' 42''.3$	$-6''.8$	Leiden A. G. Catalogue 698
2	1 49 38.13	−0.43	+33 17 54.7	−6.8	Leiden A. G. Catalogue 707
3	1 50 50.08	−0.40	+34 33 15.9	−7.1	Leiden A. G. Cataolgue 718
4	1 54 56.31	−0.40	+35 49 54.1	−7.2	Lund A. G. Catalogue 921
5	3 37 47.61	−0.55	+60 3 48.0	−8.4	Helsingfors-Gotha A. G. Catalogue 3168
6	4 13 20.12	−0.49	+63 36 50.9	−8.5	Helsingfors-Gotha A. G. Catalogue 3477

OBSERVATIONS OF COMET DELAVAN, 1913*f*

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY.

1913 La Plata M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	Log pΔ for α	Log pΔ for δ
Dec. 17	$10^{h}34^{m}51^{s}$	1	8, 8	$+0^{m}\ 7^{s}.85$	$-1'\ 27''.0$	$3^{h}\ 3^{m}19^{s}.10$	$-7°25'24''.2$	9.1987	0.6110n
18	10 7 57	3	8, 8	−0 7.50	+0 2.9	3 2 26.30	−7 19 51.2	9.0528	0.6096n
20	9 38 8	4	8, 10	+0 17.46	+2 58.3	3 0 42.39	−7 8 15.7	8.8494	0.6107n
21	8 55 14	6	8, 8	−0 17.63	+0 53.6	2 59 52.47	−7 2 25.7	8.0017n	0.6111n
22	8 47 28	7	8, 8	−0 12.37	−2 51.8	2 59 2.01	−6 56 13.8	8.2142n	0.6126n
23	8 38 35	8	8, 8	+0 17.63	−0 9.3	2 58 12.57	−6 49 50.1	8.4007n	0.6142n
26	8 58 38	9	8, 8	+0 4.51	−1 30.4	2 55 48.09	−6 29 58.3	8.6759	0.6192n
30	10 33 42	11	8, 8	+0 19.72	−0 14.4	2 52 46.37	−6 1 9.2	9.4343	0.6388n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$3^{h}\ 3^{m}\ 7^{s}.14$	$+4^{s}.11$	$-7°24'\ 16''.5$	$+19''.3$	Connected with * 2.
2	3 6 21.48	+4.12	−7 23 31.3	+19.2	Vienna-Ottakring A. G. Catalogue 728
3	3 2 29.69	+4.11	−7 21 13.3	+19.2	Connected with * 2.
4	3 0 20.84	+4.09	−7 11 33.1	+19.1	Connected with * 5.
5	3 0 5.94	+4.09	−7 12 2.3	+19.1	Vienna-Ottakring A. G. Catalogue 696
6	3 0 6.01	+4.09	−7 3 38.2	+18.9	Connected with * 5.
7	2 59 10.30	+4.08	−6 53 40.8	+18.8	Connected with * 8.
8	2 57 50.86	+4.08	−6 49 59.5	+18.8	Vienna-Ottakring A. G. Catalogue 685
9	2 55 39.53	+4.05	−6 28 46.5	+18.6	Connected with * 10.
10	2 55 53.22	+4.05	−6 25 26.1	+18.6	Vienna-Ottakring A. G. Catalogue 677
11	2 52 22.63	+4.02	−6 1 13.4	+18.6	Vienna-Ottakring A. G. Catalogue 664.

OBSERVATIONS OF COMET ZLATINSKY, 1914 *b*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1914 Ann Arbor M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	Log pΔ for α	Log pΔ for δ
May 25	$9^{h}35^{m}33^{s}$	1	8, 8	$+0^{m}\ 2^{s}.11$	$+3'\ 16''.2$	$6^{h}43^{m}43^{s}.39$	$+36°47'\ 38''.4$	9.7180	0.7620
26	8 53 4	2	8, 8	+0 8.58	+6 43.1	6 59 35.79	+34 1 25.3	9.7197	0.6952
26	9 19 37	3	8, 8	−0 28.24	+5 48.4	6 59 52.96	+33 58 20.4	9.7155	0.7305
28	9 29 6	4	8, 8	+2 21.26	+5 36.3	7 27 41.21	+28 11 4.9	9.6904	0.7420
30	9 18 19	5	8, 8	+0 8.31	−3 30.1	7 49 28.18	+22 44 14.0	9.6733	0.7350

MEAN PLACES FOR 1914.0 OF COMPARISON STARS

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$6^{h}43^{m}40^{s}.59$	$+0^{s}.69$	$+36°44'\ 11''.9$	$+10''.3$	Lund A. G. Catalogue 3528
2	6 59 26.45	+0.76	+33 54 32.7	+ 9.5	Leiden A. G. Catalogue 2956
3	7 0 20.44	+0.76	+33 52 22.6	+ 9.4	Leiden A. G. Catalogue 2963
4	7 25 19.10	+0.85	+28 5 21.0	+ 7.6	Cambridge A. G. Catalogue 3997
5	7 49 18.95	+0.92	+22 47 38.5	+ 5.7	Berlin A. G. Catalogue 3167

OBSERVATIONS OF THE MINOR PLANET FLORA (8),

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1909 ANN ARBOR M. T.		*	COMP.	Δα	Δδ	APP. α	APP. δ	LOG pΔ FOR α	LOG pΔ FOR δ
Nov. 3	9h 58m 52s	1	8, 8	−0m 30s.52	−9′ 10″.4	3h 52m 31s.87	+9° 12′ 51″.9	9.4985n	0.7055
11	9 44 54	3	8, 8	−0 13.43	−0 14.9	3 44 53.96	+8 59 53.9	9.4460n	0.6758
23	9 50 1	4	6, 7	−1 54.00	+6 23.1	3 32 21.98	+8 57 30.2	9.2379n	0.6893
27	8 16 10	5	8, 8	+0 44.94	−2 6.8	3 28 28.51	+9 2 6.5	9.4672n	0.7034

BY FRANK D. URIE.

Nov. 3	10h 23m 32s	1	8, 8	−0m 31s.45	−9′ 9″.0	3h 52m 30s.94	+9° 12′ 52″.3	9.4473n	0.6989
8	11 33 1	2	8, 8	−1 31.05	+4 50.8	3 47 49.95	+9 3 49.2	9.1293n	0.6843
11	10 15 42	3	8, 6	−0 14.79	−0 16.9	3 44 52.60	+8 59 51.9	9.3635n	0.6944
13	10 14 43	3	12, 8	−2 18.24	−2 16.9	3 42 49.16	+8 57 51.9	9.3667n	0.6947
27	8 28 26	5	8, 8	+0 44.54	−2 3.1	3 28 28.11	+9 2 10.2	9.4395n	0.7001
29	8 26 31	5	10, 8	−1 8.20	+1 26.7	3 26 35.38	+9 5 39.9	9.3935n	0.6958
30	9 20 42	5	8, 8	−2 4.31	+3 35.1	3 25 39.28	+9 7 48.3	9.2155n	0.6865

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	3h 52m 59s.48	+2s.91	+9° 21′ 48″.3	+14″.0	Leipzig II A. G. Catalogue 1457
2	3 49 18.04	+2.96	+8 58 44.8	+13.6	Leipzig II A. G. Catalogue 1436
3	3 45 4.39	+3.00	+8 59 55.3	+13.5	Leipzig II A. G. Catalogue 1409
4	3 34 12.87	+3.11	+8 50 53.0	+14.1	Leipzig II A. G. Catalogue 1338
5	3 27 40.42	+3.15	+9 3 59.5	+13.8	Leipzig II A. G. Catalogue 1299

Reduction to app. pl. of *3 for Nov. 13 is +3s.01, +13″.5
Reduction to app. pl. of *5 for Nov. 29 is +3.16, +13.7
Reduction to app. pl. of *5 for Nov. 30 is +3.17, +13.7

OBSERVATIONS OF COMET DELAVAN, 1913 *f*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY BERNHARD H. DAWSON

1914 ANN ARBOR M. T.		*	COMP.	Δα	Δδ	APP. α	APP. δ	LOG pΔ FOR α	LOG pΔ FOR δ
Oct. 21	6h 52m 43s	1	10, 8	+1m 21s.11	−1′ 25″.1	13h 51m 55s.73	+30° 18′ 36″.2	9.687	0.773
26	6 36 12	2	10, 10	−0 38.09	+6 15.7	14 12 8.66	+26 26 44.9	9.679	0.764
Nov. 1	6 22 32	3	8, 8	−0 17.24	+4 37.1	14 33 30.99	+21 54 56.5	9.667	0.763

MEAN PLACES OF COMPARISON STARS.

*	α 1914.0	RED. TO APP. PL.	δ 1914.0	RED. TO APP. PL.	AUTHORITY
1	13h 50m 33s.28	+1s.34	+30° 20′ 15″.9	−14″.6	A. G. Leiden 5040
2	14 12 45.38	+1.37	+26 20 44.0	−14.8	A. G. Cambridge E. 6774
3	14 33 46.81	+1.42	+21 50 34.1	−14.7	A. G. Berlin B. 5119

OBSERVATIONS OF COMET WESTPHAL-DELAVAN, 1913*d*.

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY

1913 La Plata M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	Log pΔ for α	Log pΔ for δ
Sept. 26	10h 29m 7s	1	8, 8	−0m 13s.17	−0′ 15″.6	21h 54m 18s.36	− 2° 34′ 27″.4	9.0654	0.6709n
27	8 15 26	3	8, 8	−0 4.00	−0 49.2	21 51 20.61	− 1 48 17.5	9.1682n	0.6802n
28	11 25 38	5	8, 8	−0 10.01	−1 32.8	21 47 40.24	− 0 50 17.9	9.4042	0.6917n
30	9 40 25	7	8, 8	−0 9.05	−2 16.7	21 41 34.75	+ 0 49 1.2	8.8718	0.7083n
Oct. 1	10 48 43	8	8, 8	−0 3.79	−0 56.5	21 38 20.63	+ 1 43 4.4	9.3518	0.7157n
2	12 21 48	10	8, 8	−0 0.14	−4 58 8	21 35 7.24	+ 2 37 51.5	9.5852	0.7162n
3	8 36 52	12	8, 8	−0 1.44	−4 1.3	21 32 37.78	+ 3 21 17.4	8.1900n	0.7341n
4	8 23 51	15	8, 8	−0 0.12	+1 30.3	21 29 44.61	+ 4 12 4.2	8.4543n	0.7421n
5	11 24 48	17	8, 8	−0 19.20	−2 37.4	21 26 31.44	+ 5 9 25.4	9.5242	0.7369n
15	9 12 20	18	8, 8	+0 8.51	+2 10.9	21 2 22.27	+13 10 58.1	9.3428	0.8028n
16	8 0 55	20	8, 8	+0 12.72	−1 16.2	21 0 26.96	+13 54 16.8	8.9353	0.8176n
17	8 5 52	22	8, 9	+0 11.68	+0 54.4	20 58 29.08	+14 39 29.2	9.0399	0.8214n
18	8 19 21	24	8, 8	−0 16.60	−3 11.9	20 56 35.50	+15 24 19.0	9.1781	0.8233n
18	8 49 45	25	8, ..	−2 25.69	....	20 56 33.23	....	9.3276	....
19	8 22 22	27	8, 8	+0 1.16	+2 41.5	20 54 47.03	+16 8 10.5	9.2291	0.8261n
19	8 59 39	28	8, 8	+0 12.28	+3 0.9	20 54 43.89	+16 9 16.1	9.3873	0.8173n
20	8 14 30	29	8, 8	+0 1.85	+0 59.1	20 53 4.05	+16 51 6.2	9.2187	0.8306n
24	8 16 45	31	8, 8	+0 8.81	+1 7.9	20 46 54.71	+19 37 46.0	9.3385	0.8396n
26	8 43 8	33	8, 8	−0 3.22	+3 39.4	20 44 14.62	+20 58 19.3	9.4656	0.8330n
27	8 20 36	36	8, 8	−0 5.08	−0 10.7	20 43 3.01	+21 36 46.7	9.4150	0.8424n
28	8 13 56	37	8, 9	−0 4.41	−0 27.1	20 41 54.56	+22 15 19.7	9.4117	0.8457n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	21h 54m 28s.07	+3s.46	− 2° 34′ 27″.7	+15″.9	Connected with * 2
2	21 58 48.83	+3.46	− 2 34 32.8	+16.2	Strassburg A. G. Catalogue 7695
3	21 51 21.19	+3.42	− 1 47 44.1	+15.8	Connected with * 4
4	21 54 53.16	+3.43	− 1 47 49.6	+16.0	Strassburg A. G. Catalogue 7678
5	21 47 46.88	+3.37	− 0 49 0.8	+15.7	Connected with * 6
6	21 50 52.06	+3.38	− 0 53 53.4	+15.9	Nicolajew A. G. Catalogue 5529
7	21 41 40.51	+3.29	+ 0 51 2.3	+15.6	Nicolajew A. G. Catalogue 5509
8	21 38 21.17	+3.25	+ 1 43 45.3	+15.6	Connected with * 9
9	21 35 20.23	+3.24	+ 1 44 44.4	+15.4	Albany A. G. Catalogue 7567
10	21 35 4.17	+3.21	+ 2 42 34.7	+15.6	Connected with * 11
11	21 36 9.29	+3.21	+ 2 47 17.5	+15.7	Albany A. G. Catalogue 7573
12	21 32 36.04	+3.18	+ 3 25 3.0	+15.7	Connected with * 13
13	21 32 36.06	+3.18	+ 3 30 48.6	+15.7	BD. + 3° 4584. Connected with * 14
14	21 36 25.19	+3.19	+ 3 30 5.9	+16.0	Albany A.G. Catalogue 7576
15	21 29 41.59	+3.14	+ 4 10 18.2	+15.7	Connected with * 16
16	21 28 48.58	+3.14	+ 4 10 38.8	+15.7	Albany A. G. Catalogue 7535
17	21 26 47.53	+3.11	+ 5 11 47.1	+15.8	Albany A. G. Catalogue 7527
18	21 2 11.08	+2.68	+13 8 30.9	+16.3	Connected with * 19
19	21 4 14.39	+2.69	+13 4 16.4	+16.4	Leipzig A. G. Catalogue 8349
20	21 0 11.60	+2.64	+13 55 16.6	+16.4	Connected with * 21
21	20 59 57.04	+2.63	+14 1 39.1	+16.4	Leipzig A. G. Catalogue 8312
22	20 58 14.80	+2.60	+14 38 18.3	+16.5	Connected with * 23
23	20 56 48.36	+2.59	+14 42 54.8	+16.4	Leipzig A. G. Catalogue 8276
24	20 56 49.54	+2.56	+15 27 14.2	+16.5	Connected with *'s 25 and 26
25	20 58 56.34	+2.58	+15 25 0.4	+16.8	Berlin A. G. Catalogue 8562
26	20 58 10.83	+2.57	+15 25 10.7	+16.8	Berlin A. G. Catalogue 8550
27	20 54 43.35	+2.52	+16 5 12.2	+16.8	Berlin A. G. Catalogue 8512
28	20 54 29.09	+2.52	+16 5 58.4	+16.8	Berlin A. G. Catalogue 8510
29	20 52 59.71	+2.49	+16 49 50.2	+16.9	Connected with * 30
30	20 52 59.56	+2.49	+16 45 44.5	+16.9	Berlin A. G. Catalogue 8493
31	20 46 43.54	+2.36	+19 36 21.0	+17.1	Connected with * 32
32	20 46 5.14	+2.36	+19 35 25.0	+17.1	Berlin A. G. Catalogue 8420
33	20 44 15.60	+2.24	+20 54 22.6	+17.3	Connected with * 34
34	20 44 29.49	+2.24	+20 54 40.4	+17.3	Berlin A. G. Catalogue 7940
35	20 43 5.89	+2.20	+21 36 40.1	+17.3	Connected with * 36
36	20 43 16.55	+2.20	+21 39 29.0	+17.3	Berlin A. G. Catalogue 7929
37	20 41 56.81	+2.16	+22 15 29.4	+17.4	Berlin A. G. Catalogue 7924

OBSERVATIONS OF COMET MOREHOUSE, 1908 *c*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1908 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
Sept. 4	$10^h\ 5^m\ 22^s$	1	11, 8	$+3^m\ 51^s.14$	$-1'\ 29''.2$	$3^h\ 15^m\ 16^s.95$	$+67°57'\ 16''.5$	0.0629	0.4109
5	9 40 16	2	8, 9	−0 20.92	−6 27.1	3 11 20.67	+68 31 38.0	0.0747	0.4765

MEAN PLACES FOR 1908.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$3^h\ 11^m\ 22^s.62$	$+3^s.19$	$+67°58'\ 54''.1$	$-8''.4$	Christiania A. G. Catalogue 567
2	3 11 38.23	+3.36	+68 38 13.5	−8.4	Connected with * 3. $\Delta\alpha = +0^m 37^s.16$, $\Delta\delta = -11' 37''.6$
3	3 11 1.07	+3.36	+68 49 51.1	−8.4	Christiania A. G. Catalogue 564

OBSERVATIONS OF THE MINOR PLANET FORTUNA (19),

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY.

1909 Ann Arbor M. T.		*	Comp.	$\Delta\alpha$	$\Delta\delta$	App. α	App. δ	Log $p\Delta$ for α	Log $p\Delta$ for δ
July 16	$12^h\ 7^m\ 9^s$	1	8, 8	$-0^m\ 4^s.17$	$+9'\ 30''.1$	$19^h\ 59^m\ 41^s.93$	$-17°52'\ 54''.5$	8.4724n	0.8809
16	12 53 1	3	8, 8	−0 45.40	+4 28.0	19 59 40.38	−17 52 59.3	8.7907	0.8802
24	12 25 15	7	8, 8	+0 12.22	−4 48.0	19 51 40.56	−18 14 28.2	9.2993	0.8710

BY GEO. A. LINDSAY.

July 16	$12^h\ 29^m\ 15^s$	1	8, 8	$-0^m\ 5^s.15$	$+9'\ 28''.9$	$19^h\ 59^m\ 40^s.95$	$-17°52'\ 55''.7$	8.1557	0.8817
19	12 42 11	4	8, 8	+0 19.32	−6 41.1	19 56 41.62	−18 1 0.9	8.8327	0.8805
21	12 40 50	6	19, 8	+0 50.02	+5 57.1	19 54 40.71	−18 6 19.6	8.8928	0.8801
23	11 31 8	6	20, 8	−1 7.64	+0 36.8	19 52 43.05	−18 11 39.9	8.5157n	0.8823

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$19^h\ 59^m\ 43^s.87$	$+2^s.23$	$-18°\ 2'\ 29''.0$	$+4''.4$	8.9 mag. Connected with * 2
2	19 57 16.62	+2.23	−18 9 28.1	+4.4	Kam. 3927
3	20 0 23.54	+2.24	−17 57 31.8	+4.5	Washington Zones 18836
4	19 56 20.03	+2.27	−17 54 24.1	+4.3	9.5 mag. Connected with * 5
5	19 56 38.33	+2.27	−17 48 7.1	+4.3	Washington A. G. Catalogue 7523
6	19 53 48.40	+2.29	−18 12 20.9	+4.2	Radcliffe, 5342
7	19 51 26.04	+2.30	−18 9 44.0	+3.8	Weisse Argelander 15791

OBSERVATIONS OF COMET NEUJMIN, 1913 *c*.

MADE AT LA PLATA WITH THE 17-INCH REFRACTOR.

BY W. J. HUSSEY.

1913 La Plata M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	log pΔ for α	log pΔ for δ
Sept. 9	$12^h\ 9^m\ 0^s$	1	8, 8	$+0^m\ 8^s.79$	$-1'\ 52''.7$	$23^h 48^m\ 5^s.46$	$+0°56'\ 57''.6$	8.6976n	0.7098n
9	12 26 26	2	8, 8	+0 12.20	−3 35.1	23 48 5.01	+0 57 36.8	8.1821n	0.7099n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$23^h 47^m 53^s.19$	$+3^s.48$	$+0°58'\ 28''.2$	$+22''.1$	Connected with * 2
2	23 47 49.33	+3.48	+1 0 49.8	+22.1	Nicolajew A. G. Catalogue 5901

OBSERVATIONS OF THE MINOR PLANET HESTIA (46),

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1909 Ann Arbor M. T.		*	Comp.	Δα	Δδ	App. α	App. δ	log pΔ	
July 9	$11^h 52^m 22^s$	1	8, 8	$-0^m\ 38^s.60$	$+7'\ 10''.9$	$18^h 22^m 12^s.57$	$-19°23'\ 37''.6$	8.9049	0.8858
10	11 12 23	2	8, 8	−0 11.95	+3 9.2	18 21 17.71	−19 24 35.2	7.9851	0.8877
12	11 45 22	3	8, 8	+0 42.04	−0 18.6	18 19 25.31	−19 26 47.0	8.9782	0.8849
15	11 15 26	5	8, 8	−0 14.39	+2 43.0	18 16 46.51	−19 30 00.1	8.8101	0.8869
16	11 01 16	6	8, 8	+0 8.23	+2 3.3	18 15 55.71	−19 31 6.4	8.6606	0.8875
18	10 16 51	8	8, 8	−0 25.61	−0 50.8	18 14 18.13	−19 33 25.5	8.3908n	0.8881
19	11 41 6	9	8, 8	−0 12.26	−5 9.8	18 13 27.78	−19 34 46.0	9.1824	0.8815

BY GEO. A. LINDSAY.

July 9	$12^h 19^m 22^s$	1	8, 8	$-0^m\ 39^s.57$	$+7'\ 14''.0$	$18^h 22^m 11^s.60$	$-19°23'\ 34''.5$	9.1248	0.8829
12	12 7 41	3	8, 8	+0 41.25	−0 19.7	18 19 24.52	−19 26 48.1	9.1428	0.8782
14	11 19 2	4	8, 8	−0 26.22	−5 7.0	18 17 38.26	−19 28 54.7	8.7881	0.8787
15	11 32 7	5	8, 8	−0 14.97	+2 41.2	18 16 45.93	−19 30 1.9	8.9788	0.8854
16	11 16 29	6	8, 8	+0 7.69	+2 2.6	18 15 55.17	−19 31 7.1	8.8704	0.8867
19	10 15 14	9	8, 8	−0 9.30	−5 6.5	18 13 30.74	−19 34 42.7	8.3217n	0.8883
21	10 25 49	10	8, 8	−0 19.93	+5 16.0	18 11 59.01	−19 37 4.1	8.3278	0.8884

MEAN PLACES FOR 1909.0 OF COMPARISON STARS.

*	α	Red. to App. Pl.	δ	Red. to App. Pl.	Authority
1	$18^h 22^m 49^s.03$	$+2^s.14$	$-19°30'\ 47''.9$	$-0''.6$	Weiss's Argelander 14395
2	18 21 27.52	+2.14	−19 27 43.8	−0.6	Connected with * 1. $\Delta\alpha = -1^m 21^s.51$, $\Delta\delta = +3'4''.1$.
3	18 18 41.12	+2.15	−19 26 27.7	−0.7	Radcliffe, 4811
4	18 18 2.31	+2.17	−19 23 47.0	−0.7	Connected with * 3. $\Delta\alpha = -0^m 38^s.81$, $\Delta\delta = +2'40''.7$.
5	18 16 58.73	+2.17	−19 32 42.5	−0.6	Connected with * 3. $\Delta\alpha = -1^m 42^s.39$, $\Delta\delta = -6'14''.8$.
6	18 15 45.29	+2.19	−19 33 8.9	−0.8	Connected with * 7. $\Delta\alpha = +0^m 7^s.18$, $\Delta\delta = +8'42''.3$.
7	18 15 38.11	+2.19	−19 41 51.2	−0.8	Weiss's Argelander 14267
8	18 14 41.55	+2.19	−19 32 33.8	−0.9	Weiss's Argelander 14250
9	18 13 37.85	+2.19	−19 29 35.2	−1.0	Weiss's Argelander 14222
10	18 12 16.76	+2.18	−19 42 19.0	−1.1	Radcliffe, 4777

OBSERVATION OF COMET CAMPBELL, 1914 *e*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY BERNHARD H. DAWSON.

1914 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR δ	FOR α
1914 Nov. 7	$7^h4^m23^s$	1	10, 10	$+0^m23^s.10$	$+1'$ 9″.4	$21^h46^m35^s.68$	$+6°\ 6'\ 13''.0$	8.646	0.713

MEAN PLACES OF COMPARISON STARS.

*	α 1914.0	RED. TO APP. PL.	δ 1914.0	RED. TO APP. PL.	AUTHORITY
1	21^h46^m 9^s.47	$+3^s.11$	$+6°\ 4'\ 43''.8$	+19.8	Connected with *'s 2 and 3
2	21 44 21.02	+3.09	+6 4 30.8	+19.7	A. G. Leipzig II 10949
3	21 48 11.11	+3.12	+6 5 31.0	+20.0	A. G. Leipzig II 10990

OBSERVATIONS OF COMET, 1910 *a*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1910 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	FOR δ
Jan. 24	$5^h58^m31^s$	1	8, 8	$-0^m16^s.60$	$+13'$ 42″.1	21^h13^m 9^s.25	$-4°40'21''.2$	9.6421	0.7788
31	6 26 24	2	5, 3	−3 54.07	−0 25.6	21 36 8.82	+2 34 7.2	9.6353	0.7669
Feb. 3	6 32 35	3	8, 5	+0 18.20	−6 48.1	21 42 46.09	+4 29 58.9	9.6383	0.7659
4	6 15 53	5	8, 8	+0 9.10	+7 59.1	21 44 39.35	+5 0 34.5	9.6367	0.7632
4	6 24 15	6	8, 8	+0 18.09	+3 9.0	21 44 39.80	+5 0 40.1	9.6376	0.7641
6	6 28 42	7	8, 8	+0 15.70	−3 45.3	21 48 12.99	+6 0 17.8	9.6397	0.7644
7	6 22 15	8	8, 8	+0 25.35	+1 23.2	21 49 51.51	+6 27 35.1	9.6396	0.7628

MEAN PLACES FOR 1910.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	$21^h13^m27^s.78$	$-1^s.93$	$-4°53'52''.6$	−10″.7	Strassburg A. G. Catalogue 7432
2	21 40 4.77	−1.88	+2 34 43.5	−10.7	Albany A. G. Catalogue 7593
3	21 42 29.76	−1.87	+4 36 57.7	−10.7	9.3 mag. Connected with * 4. $\Delta\alpha = -13^s.43$, $\Delta\delta = -4'44''.8$.
4	21 42 43.19	−1.87	+4 41 42.5	−10.7	Albany A. G. Catalogue 7602
5	21 44 32.11	−1.86	+4 52 46.1	−10.7	Albany A. G. Catalogue 7614
6	21 44 23.57	−1.86	+4 57 41.8	−10.7	Albany A. G. Catalogue 7613
7	21 47 59.13	−1.84	+6 4 13.8	−10.7	Leipzig A. G. Catalogue 10990
8	21 49 27.99	−1.83	+6 26 22.6	−10.7	Leipzig A. G. Catalogue 11000

OBSERVATIONS OF COMET METCALF, 1910*b*

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY W. J. HUSSEY

1910 ANN ARBOR M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	FOR δ
Oct. 7	$7^h48^m56^s$	1	8, 8	$-0^m 12^s.41$	$-0' \; 50''.3$	$15^h25^m59^s.67$	$+18°19' 34''.5$	9.6561	0.7234
8	7 54 53	1	8, 8	−0 7.78	+2 38.9	15 26 4.30	+18 23 3.5	9.6577	0.7274
9	8 26 1	1	8, 8	−0 2.05	+6 19.6	15 26 10.02	+18 26 44.0	9.6606	0.7548
10	7 43 44	3	8, 8	−0 37.26	−3 29.1	15 26 16.07	+18 30 16.1	9.6581	0.7273
11	7 25 11	3	8, 8	−0 30.07	+2 41.9	15 26 35.80	+18 42 1.8	9.6543	0.7154

MEAN PLACES FOR 1910.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	$15^h26^m11^s.74$	$+0^s.34$	$+18°20' 24''.7$	$+0''.1$	9.5 mag. Connected with *2. $\Delta\alpha = +1^m47^s.95$; $\Delta\delta = +0'49''.5$.
2	15 24 23.79	+0.34	+18 19 35.3	+0.0	Berlin A. G. Catalogue 5554
3	15 26 53.00	+0.33	+18 33 45.6	−0.4	9.3 mag. Connected with *4. $\Delta\alpha = -0^m12^s.54$; $\Delta\delta = -5'34''.9$.
4	15 27 5.54	+0.33	+18 39 20.5	−0.4	Berlin A. G. Catalogue 5567

Reduction to apparent place: *1 Oct. 8, $+0^s.34$, $-0''.2$; Oct. 9, $+0^s.33$, $-0''.3$.
*3 Oct. 11, +0.33, −0.6.

OBSERVATIONS OF COMET GALE, 1912*a*.

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY

1912 LA PLATA M. T.		*	COMP.	$\Delta\alpha$	$\Delta\delta$	APP. α	APP. δ	LOG $p\Delta$ FOR α	FOR δ
Sept. 17	$6^h59^m41^s$	1	10, 5	$+2^m11^s.40$	$+3' \; 56''.5$	$14^h26^m58^s.47$	$-25° \; 5' 16''.7$	9.6819	0.5085n
19	6 53 46	2	10, 8	+0 24.47	−0 43.2	14 36 31.01	−22 15 23.5	9.6692	0.5347n
20	6 43 25	3	10, 8	−0 13.09	−2 3.0	14 40 59.41	−20 50 25.4	9.6499	0.5311n
20	7 12 19	3	8, 8	−0 7.91	−0 19.9	14 41 4.59	−20 48 42.3	9.6768	0.5669n

BY H. J. COLLIAU.

Sept. 20	7 30 55	3	8, 8	$-0^m \; 4^s.67$	$+0' \; 47''.5$	$14^h41^m \; 7^s.83$	$-20°47' 34''.9$	9.6900	0.5894n

MEAN PLACES FOR 1912.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED TO APP. PL.	AUTHORITY
1	$14^h24^m46^s.14$	$+0^s.93$	$-25° \; 8' 59''.4$	$-13''.8$	Cordoba General Catalogue 19614
2	14 36 5.53	+1.01	−22 14 27.1	−13.2	Cordoba General Catalogue 19885
3	14 41 11.46	+1.04	−20 48 9.5	−12.9	Cordoba General Catalogue 20010

OBSERVATIONS OF COMET ZINNER-GIACOBINI, 1913e

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY

1913	LA PLATA M. T.	*	COMP.	Δα	Δδ	APP. α	APP. δ	LOG pΔ FOR α	LOG pΔ FOR δ
Oct. 28	8h 50m 19s	1	8, 8	−0m 11s.09	+0′ 37″.0	19h 6m 8s.75	− 9°17′ 59″.0	9.6375	0.6442n
29	8 53 18	3	8, 8	−0 2.78	+0 51.1	19 11 12.74	−10 15 33.6	9.6406	0.6383n
30	8 48 27	5	8, 8	−0 18.33	−1 22.8	19 16 22.52	−11 13 40.4	9.6360	0.6279n
31	8 14 5	6	8, 8	+0 9.75	+2 53.8	19 21 32.63	−12 11 8.0	9.5939	0.5991n
31	8 48 52	7	11,—	−1 42.98	....	19 21 40.47	....	9.6366	....
Nov. 1	8 26 47	8	8, 8	+0 12.93	+1 32.0	19 27 0.89	−13 11 13.4	9.6109	0.5960n
1	9 3 58	9	14,—	+1 4.32	....	19 27 9.35	....	9.6503	....
2	7 48 32	10	8, 8	−0 13.04	+1 47.4	19 32 24.82	−14 9 46.2	9.5506	0.5586n
6	8 40 48	12	8, 8	+0 17.70	−3 34.0	19 56 4.85	−18 15 13.4	9.6277	0.5460n
8	8 49 44	13	8, 8	+0 14.12	−5 39.9	20 8 37.53	−20 17 15.0	9.6383	0.5269n
16	9 25 33	15	8, 8	−0 2.34	+3 28.9	21 3 44.02	−27 56 56.6	9.6782	0.4439n
18	8 32 53	17	8, 8	−0 0.68	−1 49.7	21 18 15.57	−29 35 53.1	9.6010	0.2740n
18	8 59 20	18	14,—	+1 41.17	....	21 18 23.80	....	9.6441	....
19	8 27 9	19	8, 8	+0 18.71	+2 37.4	21 25 46.29	−30 23 49.9	9.5870	0.2252n
29	9 34 4	21	8, 8	+0 22.18	−0 12.6	22 43 19.76	−36 18 35.8	9.6670	0.1281n

MEAN PLACES FOR 1913.0 OF COMPARISON STARS.

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	19h 6m 17s.50	+2s.34	− 9°18′ 35″.6	−0″.4	Connected with * 2
2	19 6 35.32	+2.34	− 9 15 39.7	−0.4	Vienna-Ottakring A. G. Catalogue 6607
3	19 11 13.14	+2.38	−10 16 24.4	−0.3	Connected with * 4
4	19 11 36.14	+2.38	−10 14 10.9	−0.3	Harvard A. G. Catalogue 6691
5	19 16 38.44	+2.41	−11 12 17.4	−0.2	Harvard A. G. Catalogue 6747
6	19 21 20.43	+2.45	−12 14 1.6	−0.2	Connected with * 7
7	19 23 20.99	+2.46	−12 19 10.2	−0.0	Harvard A. G. Catalogue 6802
8	19 26 45.48	+2.48	−13 12 45.3	−0.1	Connected with * 9
9	19 26 2.55	+2.48	−13 9 50.8	−0.1	Harvard A. G. Catalogue 6830
10	19 32 35.33	+2.53	−14 11 33.7	+0.1	Connected with * 11
11	19 32 54.44	+2.53	−14 9 7.0	+0.1	Washington A. G. Catalogue 7369
12	19 55 44.45	+2.70	−18 11 39.7	+0.3	Bordeaux 6023
13	20 8 20.62	+2.79	−20 11 35.6	+0.5	Connected with * 14
14	20 8 20.18	+2.79	−20 8 58.7	+0.5	Cincinnati Zone Catalogue 3359
15	21 3 43.19	+3.17	−28 0 27.5	+2.0	Connected with * 16
16	21 1 40.76	+3.16	−28 0 43.8	+1.8	Argentine General Catalogue 28937
17	21 18 12.98	+3.27	−29 34 5.9	+2.5	Connected with * 18
18	21 16 39.37	+3.26	−29 32 7.6	+2.4	Argentine General Catalogue 29281
19	21 25 24.27	+3.31	−30 26 30.0	+2.7	Connected with * 20
20	21 24 54.82	+3.31	−30 30 1.0	+2.6	Cordoba Zone Catalogue 703
21	22 42 53.91	+3.67	−36 18 29.0	+5.8	Connected with * 22
22	22 46 52.16	+3.69	−36 21 1.1	+6.0	Argentine General Catalogue 31110

OBSERVATIONS OF COMET CAMPBELL, 1914 *e*.

MADE WITH THE 17-INCH REFRACTOR OF LA PLATA OBSERVATORY.

BY W. J. HUSSEY.

1914	LA PLATA M. T.	*	COMP.	Δα	Δδ	APP. α	APP. δ	LOG pΔ FOR α	LOG pΔ FOR δ
Sept. 24	$9^h\ 4^m\ 34^s$	1	8, 8	$+0^m\ 11^s.90$	$-1'\ 41''.1$	$0^h\ 38^m\ 44^s.30$	$-49°\ 2'\ 17''.0$	9.7610n	9.4431
24	9 20 22	2	8, 8	−0 6.15	−3 12.4	0 38 27.16	−49 0 13.9	9.7261n	9.6705
26	10 4 36	3	.. 2	....	+6 39.9	....	−42 14 50.0	....	9.8983
26	12 50 6	4	8, 8	+0 27.84	+1 9.2	23 51 10.32	−41 51 17.1	9.3495	0.0241
26	13 7 3	5	8, 8	−0 7.23	−4 56.0	23 50 57.57	−41 49 0.6	9.4052	9.8430
27	7 12 25	6	8, 8	−0 31.34	−1 1.5	23 38 2.39	−39 14 25.6	9.7335n	0.2087n
28	7 53 2	8	8, 8	−0 21.21	+3 23.1	23 22 47.41	−35 41 44.5	9.5266	0.0369n
Oct. 2	7 59 3	10	.., 4	....	+0 28.2	....	−24 13 9.4	....	0.2838n
2	8 11 30	10	6, ..	+2 27.47	....	22 42 15.66	....	9.3773n	....
5	8 19 37	11	9, 8	+0 54.43	+5 59.4	22 24 9.29	−17 36 18.0	9.1768n	0.4292n
6	8 48 56	12	8, 8	−0 11.99	+1 2.3	22 20 47.80	−15 36 48.2	8.8502n	0.4530n
7	7 57 50	14	8, 8	−0 17.33	−2 47.5	22 16 54.14	−13 59 46.1	9.2083n	0.5061n
9	8 2 30	16	8, 8	−0 11.42	+0 38.1	22 10 5.35	−11 2 31.2	9.0790n	0.5532
10	8 37 0	18	8, 8	−0 5.90	−4 50.7	22 7 5.70	−9 45 51.5	8.5066n	0.5696n
11	7 54 9	19	8, 8	+0 24.57	−2 37.1	22 4 43.29	−8 33 5.0	9.0373n	0.5916n
11	8 23 27	20	12, 8	−0 37.08	−2 42.3	22 4 40.02	−8 31 38.5	8.6744n	0.5895n

MEAN PLACES FOR 1914.0 OF COMPARISON STARS

*	α	RED. TO APP. PL.	δ	RED. TO APP. PL.	AUTHORITY
1	$0^h\ 38^m\ 27^s.40$	$+5^s.00$	$-49°\ 1'\ 2''.0$	$+26''.1$	Connected with * 2 $\Delta\alpha = -0^m 0^s.91$, $\Delta\delta = -3' 34''.4$
2	0 38 28.31	+5.00	−48 57 27.6	+26.1	Argentine General Catalogue 643
3	23 56 42.15	+4.93	−42 21 52.3	+22.4	Argentine General Catalogue 32366
4	23 50 37.55	+4.93	−41 52 48.3	+22.0	Delavan La Plata Meridian Circle 2 obs.
5	23 50 59.88	+4.92	−41 44 26.7	+22.1	Argentine General Catalogue 32270
6	23 38 28.87	+4.86	−39 13 45.1	+21.0	Connected with * 7 $\Delta\alpha = -0^m 0^s.90$, $\Delta\delta = -2' 53''.5$
7	23 38 37.87	+4.86	−39 10 51.6	+21.0	Cordoba Zone Catalogue 994
8	23 23 3.87	+4.75	−35 45 27.6	+20.0	Connected with * 9 $\Delta\alpha = -0^m 50^s.11$, $\Delta\delta = -1' 43''.5$
9	23 23 53.98	+4.75	−35 43 44.1	+20.0	Argentine General Catalogue 31774
10	22 39 43.83	+4.36	−24 12 58.4	+17.2	Argentine General Catalogue 30961
11	22 23 10.73	+4.13	−17 42 34.3	+16.9	Washington A. G. Catalogue 8381
12	22 20 55.72	+4.07	−15 38 7.6	+17.1	Connected with * 13 $\Delta\alpha = -0^m 5^s.00$, $\Delta\delta = +5' 58''.5$
13	22 21 0.72	+4.07	−15 44 6.1	+17.1	Washington A. G. Catalogue 8364
14	22 17 7.46	+4.01	−13 57 16.8	+18.2	Connected with * 15 $\Delta\alpha = -0^m 32^s.52$, $\Delta\delta = -3' 54''.5$
15	22 17 39.98	+4.01	−13 53 22.3	+18.2	Washington A. G. Catalogue 8347
16	22 10 12.86	+3.91	−11 3 26.6	+17.3	Connected with * 17 $\Delta\alpha = +2^m 56^s.20$, $\Delta\delta = +3' 51''.2$
17	22 7 16.67	+3.90	−11 7 17.5	+17.0	Harvard A. G. Catalogue 7835
18	22 7 7.75	+3.85	−9 41 18.2	+17.4	Harvard A. G. Catalogue 7834
19	22 4 14.91	+3.81	−8 30 45.4	+17.5	Connected with * 20 $\Delta\alpha = -1^m 58^s.38$, $\Delta\delta = -1' 31''.7$
20	22 6 13.28	+3.82	−8 29 13.8	+17.6	Vienna Ottakring A. G. Catalogue 7943

OBSERVATION OF COMET MELLISH, 1915 *a*.

MADE AT ANN ARBOR WITH THE 12¼-INCH REFRACTOR.

BY BERNHARD H. DAWSON.

1915 Ann Arbor M. T.			*	Comp.	Δα	Δδ	App. α	App. δ	Log pΔ for α	Log pΔ for δ
Feb.	17	15ʰ 13ᵐ 45ˢ	1	8, 8	+0ᵐ 31ˢ.15	−9′ 5″.2	17ʰ 12ᵐ 8ˢ.51	+2° 37′ 7″.6	9.586n	0.758
	17	15 44 7	2	8, 8	+0 16.63	+9 58.3	17 12 10.05	+2 37 0.7	9.551n	0.757
	19	14 58 24	4	8, 8	−0 3.56	−7 12.5	17 14 40.09	+2 28 2.7	9.595n	0.771
Mar.	12	13 56 56	6	8, 8	+0 5.70	−7 2.4	17 41 4.25	+0 44 5.8	9.600n	0.768
Apr.	3	13 2 32	7	8, 8	+0 35.13	+4 6.5	18 8 25.93	−2 4 7.1	9.596n	0.777
	7	13 16 34	9	8, 8	−0 29.48	−10 28.7	18 13 27.75	−2 50 3.7	9.571n	0.782
	8	13 16 49	10	10, 10	+0 8.13	+9 50.8	18 14 43.40	−3 2 34.8	9.568n	0.783
	10	13 58 50	11	10, 10	+0 31.30	−9 25.4	18 17 17.84	−3 29 26.9	9.498n	0.789
	10	14 32 31	13	—, 3t	....	+7 44.9	....	−3 30 4.6	......	0.792
	11	12 38 3	14	8, 8	−0 43.86	−3 51.2	18 18 29.64	−3 43 4.7	9.599n	0.792
	11	14 11 31	14	8, 8	−0 38.92	−4 48.0	18 18 34.58	−3 44 1.5	9.468n	0.792
	13	13 47 41	15	7t, —	+1 17.32	....	18 21 7.28	....	9.503n	.....
	13	14 10 51	16	8, 8	−0 8.80	+1 19.8	18 21 8.57	−4 14 17.1	9.458n	0.795
	16	12 31 53	17	8, 8	+0 16.40	+2 17.8	18 24 56.68	−5 3 33.3	9.594n	0.787
	16	14 16 12	17	8, 8	+0 21.96	+0 59.3	18 25 2.24	−5 4 51.8	9.428n	0.801
May	10	13 41 22	18	8, 8	−0 1.97	+6 20.1	19 2 10.63	−18 45 53.7	9.389n	0.866
	17	14 14 6	19	8, 8	+0 45.30	+0 54.5	19 19 16.41	−27 32 53.2	9.252n	0.905

MEAN PLACES OF COMPARISON STARS.

*	α 1915.0	Red. to App. Pl.	δ 1915.0	Red. to App. Pl.	Authority
1	17ʰ 11ᵐ 36ˢ.80	+0ˢ.56	+2° 46′ 29″.8	−17″.0	A. G. Albany 5706
2	17 11 52.85	+0.57	+2 27 19.3	−16.9	Connected with * 3
3	17 11 57.28	+0.57	+2 16 51.2	−16.9	A. G. Albany 5708
4	17 14 43.05	+0.60	+2 35 32.2	−17.0	Connected with * 5
5	17 15 20.88	+0.60	+2 38 48.0	−17.0	A. G. Albany 5730
6	17 40 57.44	+1.11	+0 51 25.3	−17.1	A. G. Nicolajew. 4400
7	18 7 49.14	+1.66	−2 7 58.9	−14.7	Connected with * 8
8	18 7 42.64	+1.66	−2 16 43.8	−14.7	A. G. Strassburg 6091
9	18 13 55.48	+1.75	−2 39 20.8	−14.2	A. G. Strassburg 6121
10	18 14 33.48	+1.79	−3 12 11.6	−14.0	A. G. Strassburg 6129
11	18 16 44.71	+1.83	−3 19 47.7	−13.8	Connected with * 12
12	18 16 55.23	+1.83	−3 8 43.9	−13.8	A. G. Strassburg 6139
13	18 19 35.32	+1.83	−3 37 35.9	−13.6	A. G. Strassburg 6159
14	18 19 11.65	+1.85	−3 39 0.0	−13.5	Connected with * 13
15	18 19 48.04	+1.92	−4 8 2.0	−13.2	A. G. Strassburg 6161
16	18 21 15.46	+1.91	−4 15 23.8	−13.1	Connected with * 15
17	18 24 38.28	+2.00	−5 5 38.8	−12.3	A. G. Strassburg 6182
18	19 2 9.84	+2.76	−18 52 9.8	−4.0	Argentine General Catalogue 26165
19	19 18 27.99	+3.12	−27 33 48.1	+0.4	Argelander-Oeltzen 19467

REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY DURING THE YEAR 1912

By WALTER M. MITCHELL

The seismographic equipment of this observatory has been described in a previous number of this publication. The seismographs have been in constant operation during the past year, and have probably recorded all the severe earthquakes wherever occurring, besides numerous minor disturbances and microseisms. The total number of distinct shocks recorded is eighteen; of these, the most severe was that of July 7th.

There have been few changes in the adjustments of the instruments. The periods of the pendulums of the Bosch Tromometers have been adjusted so that now both have the same value, approximately 12 seconds. The Wiechert Vertical Seismograph made a feeble response to our efforts at adjustment, and has yielded two very small records,—this was in the early part of the year. Since then it has relapsed to its former state of inefficiency. The principal fault seems to be one of design; the instrument apparently lacks sensitiveness.

Microseismic disturbances have been less numerous during the year 1912, than during the preceding years. This is particularly true of the short period, or "regular" microseisms. The irregular microseisms of the type shown in Figures 3 and 4, Plate XIII of this volume, have been proportionately more frequent than in the preceding period.

As before noted all types of microseisms are more frequently recorded during the winter months than at any other time of year. The irregular microseisms have been almost invariably recorded during the coldest weather, at the times when the surface of the ground is frozen. During January and February these tremors were almost continuous, and those months were by far the coldest of the year. Similarly during a short period of cold weather in the month of December, these irregular microseisms were conspicuous on the seismograph records. One feature in connection with these tremors has been particularly noted, namely, that the strongest irregular tremors are almost invariably recorded during the early hours of the day; that is during the three or four hours after 8 a. m., at which time the sheets are changed. This seems to indicate that there is some connection between these tremors and the daily rise in the temperature resulting from the appearance of the sun above the horizon. The presence of actual sunshine does not seem to be essential, as is learned from a comparison of the record of microseisms with the meterological record. However, the daily rise in temperature takes place regardless of actual sunshine, so that the absence of this would not necessarily preclude the heating effect as a contributing cause. It seems more likely that the causes of these irregular microseisms will be found in the changes of the temperature of the air, and in the barometric pressure rather than in any change in the actual temperature of the surface of the ground. That the causes are atmospheric is supported by Klotz' investigations of the correlation between microseisms observed at Ottawa and barometric pressures over the neighboring regions. It seems safe to assume that the surface of the ground must be in a proper condition to render changes of atmospheric conditions effective. The frozen condition of the ground is probably a contributing cause, but is apparently not sufficient in itself to produce microseisms of this character, for frequently the seismograph records nothing unusual when the surface of the ground is hard frozen.

The interpretation of these particular types of disturbances recorded by the seismograph is one of great difficulty, as there are probably many factors which modify the appearance of the actual record. The problem is one of great interest, but it is one that can only be solved by cooperation, and by the comparison of records and observations made at many stations. It is hoped that the present type of seismograph will be ma-

terially improved, so that the seismogram will be a record of the actual movement of the earth particle, free from the spurious vibrations and tremors due to the swinging of the pendulum.

The data referring to the several shocks recorded and to the microseisms are given below. The manner of presenting this data, and the notation used, follow the scheme employed in the former paper with the exception that in accordance with the customs of other observatories the times of the phase "K" (end of long waves) have been omitted. All times are given in Central Standard Time, midnight to midnight; to obtain Greenwich civil time add six hours. Remarks follow, which give the nature and the peculiarities of the record of the shock.

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	F	A	Δ
	1912		h m	h m	h m	h m	h m	m.m.	mgm.
77	Jan. 31	B—EW	14 20.0	14 26.2	14 34.3	14 34.6	15 7	18.1	5.0
		B—NS	14 19.9	14 26.1	14 34.3	14 35.0	15 12	12.0	
		W—EW	14 21.1	14 25.9	14 34.0	14 34.9	14 50	5.0	
		W—NS		14 25.3	14 33.9	14 34.3	14 48	4.0	
78	Mar. 11	B—EW		4 35.3	4 39.2	4 40.0	5 17	15.5	
		B—NS			4 38.0	4 40.0	5 16	15.1	
		W—V			4 38.8			0.2	
79	May 6	B—EW	13 9.5	13 14.2	13 24.0	13 26.1	14 7	25.1	4.7
		B—NS	13 9.4	13 14.2	13 25.0	13 27.2	14 7	36.1	
		W—EW		13 14.2	13 23.8	13 24.5	13 5	5.2	
		W—NS	13 9.5	13 14.4	13 24.9	13 25.2	13 4	6.1	
		W—V			13 24.2			0.4	
80	May 22	B—NS	20 46.5	21 12.5	21 29.1	21 35.7	22 18	6.0	
81	June 8	B—EW		0 13.0	0 16.0			1.1	
		B—NS		0 12.8	0 16.8			3.0	
82	June 8	B—EW	1 45.7	1 54.5	2 2.3	2 3.3		37.1	
		B—NS	1 50.7	1 59.8	2 2.3	2 3.7		24.2	
83	June 10	B—EW	10 12.6	10 23.0	10 32.8	10 33.1	11 14	11.1	6.5
		B—NS	10 12.5	10 23.0	10 32.6	10 32.8	11 14	14.9	
		W—EW	10 14.6	10 25.0	10 34.7	10 34.9	11 6	3.1	
		W—NS	10 14.6	10 25.0	10 34.8	10 34.9	11 5	3.2	
84	June 12	B—EW	6 49.5	6 54.3	6 57.1	6 57.4	7 16	4.0	3.1
		B—NS	6 49.3	6 54.1	7 0.1	7 1.1	7 15	4.0	
		W—EW	6 49.7	6 54.3	6 57.3		7 4	2.5	
		W—NS	6 49.5	6 54.3	6 59.8	7 1.2	7 5	1.5	
85	July 7	B—EW	3 5.9	3 12.3	3 20.0		4 15	>72.0	4.4
		B—NS	3 7.3	3 13.8	3 21.0		4 20	>71.0	
86	July 8	B—EW	16 2.7	16 9.0†	16 16.8	16 20.5	16 41	16.2	4.5
		B—NS	16 3.2	16 9.7†	16 17.8	16 20.8	16 46	15.8	
		W—EW	16 2.8	16 8.9†	16 17.6	16 18.0	16 36	19.8	
		W—NS	16 2.7	16 9.2†	16 17.3	16 20.3	16 33	14.8	
87	Aug. 8	B—EW	19 51.8	20 2.1†	20 17.3	20 20.3	20 55	10.0	8.1
		B—NS	19 51.7	20 1.1†	20 10.6	20 18.4	21 6	9.0	
		W—EW	19 51.0	20 2.2	20 17.0	20 17.2	20 55	3.8	
		W—NS	19 51.7	20 2.2	20 12.2	20 17.4	20 56	2.5	
88	Aug. 18	B—EW	15 21.4	15 23.0	15 24.9*	15 25.3	15 29	3.0	1.8
		B—NS		15 21.7	15 24.9*		15 30	1.1	
		W—EW		15 22.3*	15 24.3		15 28	4.0	
		W—NS		15 22.3*	15 24.3		15 24	1.5	
89	Sept. 10	B—EW		10 18.6	10 20.4	10 20.5	10 23	5.3	1.4
		B—NS		10 18.5	10 20.4	10 20.5	10 22	2.0	
		W—EW		10 17.5	10 19.4	10 19.5	10 21	4.4	

NO.	DATE	INSTRUMENT COMPONENT	P	S	L	M	F	A	Δ
	1912		h m	h m	h m	h m	h m	m.m.	mgn.
90	Sept. 29	B—EW			15 55.0		16 6	0.2	
		B—NS			15 56.9	15 58.3	16 7	0.5	
91	Nov. 7	B—EW	1 48.8*	1 55.5*	1 59.3*		2 52	7.8	3.7
		B—NS	1 48.7*	1 55.5	1 59.2*		2 38	7.5	
		W—EW	1 49.0*	1 55.5*	1 59.2		2 39	3.0	
		W—NS	1 49.0*	1 55.6*	1 59.3		2 38	3.0	
92	Nov. 19	B—EW		8 0.8	8 5.5*		8 29	5.5	
		B—NS		8 0.8	8 5.5*		8 28	8.5	
		W—EW		8 0.6	8 5.3		8 28	3.0	
		W—NS		8 0.6	8 5.3		8 28	4.0	
93	Dec. 7	B—EW			17 6.1*		17 14	2.0	
		B—NS			17 5.8*		17 11	1.8	
		W—EW			17 6.0*		17 13	2.3	
		W—NS			17 6.1*		17 11	1.5	
94	Dec. 9.	B—EW		2 44.6	2 51.0		3 7	5.1	4.4
		B—NS	2 38.2	2 43.6	2 52.4	2 52.6	3 8	26.0	
		W—EW	2 38.2	2 43.9	2 50.3		3 7	2.5	
		W—NS		2 44.3	2 52.3		3 7	4.0	

REMARKS

77. According to newspaper reports this shock occurred in Alaska. Agreement in distance good.

78. Preliminaries are very indistinct. Hence times are uncertain, and no estimate is made of distance. Slight record on Wiechert Vertical. No record on Wiechert Horizontal.

79. Distance is somewhat uncertain as P is not clearly marked. Two main shocks. Second follows first after an interval of three minutes. Recorded on Wiechert Vertical Siesmograph.

80. Preliminaries are very uncertain, hence no attempt is made to determine the distance. Shock consists of four groups of waves or pulses, at intervals of about 2.5 minutes. Time signals are defective on B-EW and both Wiechert records, hence these cannot be read.

81. Continuous tremors and small shocks during the previous day. See in record of microseisms.

82. This shock while quite severe is very unsatisfactory, as it is quite impossible to differentiate the phases owing to continuous tremors. The hour signals on the Wiechert record are nearly all missing. Consequently no times can be given for this instrument. B-EW time signals are very faint and uncertain. Another smaller shock followed at about 7 hrs, but all time signals are missing.

83. Distance probably not accurate.

84. Times a little uncertain owing to incomplete clock signals. Record in both instruments is so similar that it is conspicuous. Distance fairly accurate.

85. A severe shock. Recording pen swung off sheets from 3 hrs 25 min to 3 hrs 28 min. Wiechert Horizontal out of order, hence no record. Distance fairly accurate.

86. Preliminaries are not well marked, but distance seems to be accurate. Times may not be accurate as signal clock was moved to a new location during this day.

87. Distance is probably not accurate.

88. A very small disturbance, probably not far distant. Times are somewhat uncertain owing to irregularity of signal clock.

89. A very small disturbance, mainly in the EW component. Not recorded on W-NS.

90. This disturbance consists of sine curves of small amplitude. No preliminaries are visible. Only faint traces of this shock on the Wiechert record.

91. Preliminaries are well marked. Main waves consist of irregular tremors without the characteristic maximum. A second impulse fol-

lows at 2 hrs 5.5 min. Direction of movement SE-NW. Distance not accurate.

92. P is not distinguishable. A single sharp impulse at L, followed by irregular tremors of small (2-3mm) amplitude.

93. No preliminaries visible. Small irregular tremors frequent all during the day. Shock commences with a single impulse, direction NE-SW. End of tails lost in microseisms.

94. A decided shock. Movement almost entirely NS. Distance accurate.

MICROSEISMS.

1912.

Jan. 1-2.

Slight irregular tremors during the day. These show most prominently on B — E W record.

Jan. 2-3.

The same tremors are continued.

Jan. 3-4.

Strong irregular tremors on both Bosch records. Stronger in E W component until Jan. 4. o hrs. when the N S component becomes stronger. No traces of these tremors on the Weichert records.

Jan. 4-5.

Strong irregular tremors continued. These die out in E W component by Jan. 4, 18 hrs., but continue with only slightly diminished intensity in the N S. No traces on the Weichert record.

Jan. 5-6.

Moderately strong irregular tremors on both Bosch records. Scattered groups of short period microseisms on the N S record. No traces on Weichert record.

Jan. 6-7.

Strong irregular tremors on Bosch records during the early part of this period.

Jan. 7-8.

Tremors continued.

Jan. 8-9.

Tremors continued. But on B — E W these are much diminished after Jan. 8, 17 hrs. Nothing on Weichert records.

Jan. 9-10.

Occasional tremors during the day, but intensity is much diminished.

Jan. 12-13.

Irregular tremors. Stronger in early part of this period on E W record.

Jan. 13-14.

Moderately strong irregular tremors on B — E W, but not on B — N S. Weichert shows nothing.

Jan. 14-17.

Tremors continued. N S component increasing in strength.

Jan. 17-18.

Intensity of tremors much reduced.

Jan. 19-20.

Occasional irregular tremors of small intensity.

Jan. 20-22.

Tremors continue, gradually increasing in strength.

Jan. 29-30.

Occasional irregular tremors with short period microseisms, the latter are stronger on N S record. Faint traces on Weichert.

Feb. 1-4.

Irregular tremors during this period. These become very strong on Feb. 4.

Feb. 4-5.

Irregular tremors continue, but with diminishing intensity.

Feb. 5-8.

Continuous irregular tremors of small intensity.

Feb. 8-9.

Intensity of tremors diminishing. There have been no traces of these on the Weichert records.

Feb. 12-14.

Continuous irregular tremors, intensity diminishing towards the end of this period. Tremors are more conspicuous on E W record. No traces on Weichert.

Feb. 21-24.

Continuous irregular tremors of small intensity during this period. More conspicuous on E W record. Faint traces on Weichert.

Aug. 22-23.

Scattered groups of regular microseims on B — E W record. Traces of these on W — E W.

Sept. 16-17.

Regular microseisms of small amplitude on B — E W record.

Sept. 29-30.

Slight traces of irregular tremors on both Bosch records.

Nov. 3-4.

Faint traces of regular microseisms with very small amplitude. These show on the Weichert records.

Nov. 7.

A series of regular tremors beginning at 10 hrs. 55 min. continuing for 9 min. These commence again at 11 hrs. 42 min. and continue for 10 min. This was probably a small shock, but phases cannot be distinguished. Amplitude less than 0.5 mm. These tremors are most conspicuous on B — E W, only very slight traces on Weichert record.

Nov. 13-14.

Irregular tremors of small amplitude on B — N S.

Nov. 14-15.

Irregular tremors continue on B — N S. Supporting pier shifts during day, indicated by decided "drift" of recording pen.

Nov. 16-19.

Irregular tremors on B — N S continue.

Nov. 21-22.

Slight tremors on B — E W, these appear also on B — N S, with traces on Wiechert records.

Nov. 23-24.

Slight irregular tremors on B — N S.

Nov. 28-29.

Tremors begin at the end of this period. These are generally irregular and quite prominent on B — N S. Conspicuous on Wiechert records.

Nov. 29-30.

Tremors continue through this period, diminishing in intensity at the end.

Dec. 2-3.

Faint traces of irregular tremors on B — N S.

Dec. 6-7.

Strong irregular tremors during the early portion of this period, gradually diminishing in intensity. Conspicuous on B — N S, but not recorded on B — E W. Not recorded on Wiechert instruments.

Dec. 7-8.

Small irregular microseisms. These are more conspicuous on B — E W than on B — N S. The Wiechert records also show distinct tremors.

Dec. 9-12.

Conspicuous irregular microseisms on B — N S. These show slightly on B — E W. Intensity diminishes during latter portion of period.

Dec. 12-13.

Very strong irregular tremors on the morning of the 12th. These are strong on the B — N S record, with only traces on the B — E W. Wiechert records do not show these tremors.

Dec. 13-14.

Tremors continue, but with greatly diminished intensity.

Dec. 22-23.

Slight irregular tremors on B — N S.

Dec. 25-26.

Short period regular microseisms. These are equally prominent on both Bosch records. Traces on W — E W. Line traced by pen of Wiechert Vertical is very uneven in intensity, but no tremors.

Dec. 28-30.

Scattered short period regular microseisms on both Bosch records.

Dec 31-Jan. 1.

Scattered regular microseisms continue. Traces on Wiechert records.

THE REGISTRATION OF EARTHQUAKES AT THE DETROIT OBSERVATORY DURING THE YEAR 1913

By PAUL W. MERRILL

The equipment of this seismological station has been described in the reports for preceding periods. The disposition and constants of the instruments have not been altered.

NO.	DATE	INST. COMP.	P	S	L	M	F	A	Δ
	1913		h m	h m	h m	h m	h m	mm.	1000 km.
95	Jan. 15	B—EW				6		small	
		B—NS				13 7		small	
96	Mar. 4	B—EW			6 38.1			0.3	
		B—NS		remark	37.8			0.2	
97	Mar. 8	B—EW	9 58.5	10 3.7	10 7.1	10 9.4	>10 30	3.0	
		B—NS	59.0	3.4	6.7	7.5		0.4	3
		W—EW			7.0	8.2		0.9	
98	Mar. 14	B—EW	3 5.4	3 23.1	3 42.4?	3 44.3	4 16	0.7	
		B—NS	4.	17.0	42.1	42.8	15	0.7	13
		W—EW	4.	23.0	42.1	44.1	31	0.9	
		W—NS	4.4	23.1	42.2	44.0	42	0.6	
99	Mar. 30	B—EW	21 51.6*		22 14.9	22 18.7	>22 50	0.7	
		B—NS	51.4*		18.5	19.0	> 50	1.2	8
		W—EW	51.5*		14.0	18.4	>23 0	0.7	
		W—NS	51.5*		13.9	18.0	> 0	0.8	
100	May 16	B—EW				6 17.5		0.2	
		B—NS				17.5		0.2	
101	May 30	B—EW				6 55	> 7 8	1.2	
		B—NS				54	> 9	0.5	
102	June 14	B—EW	2 43.2			3 4.1		0.3	
		B—NS	42.7			3.4		0.2	
103	June 25	B—EW	23 16.0	23 30.7†	23 46.2*	23 55.9	1 30	1.9	
		B—NS		30.8		56.7	0 39	0.5	11
		W—EW				56			
104	July 8	B—EW		18 22.8	18 25.8	18 26.0	18 32	2.5	
		B—NS		22.3	25.2	25.4	35	0.9	
		W—EW		22.8	25.7	26.0	32	0.4	2
		W—NS			25.5	25.8	26	0.1	
105	July 25	B—EW		6 50.4	6 53.6	6 55.2	7 10	1.5	
		B—NS		50.1	54.4	56.7	9	0.7	2+
106	Aug. 6	B—EW	16 27.1	16 32.2	16 38.6	16 44.2	17 48	9.8	
		B—NS	23.9	31.8	41.0	48.3	45	12.0	
		W—EW		33.8		44.0	16 58	1.0	5
		W—NS		31.1	41.2	48.2	17 1	1.1	
		W—V				50.2		1.	
107	Oct. 1	B—EW		22 35.2	22 38.9	22 42.6	23 4.9	4.1	
		B—NS	22 29.4	34.7	40.6	45.3	3.4	1.5	3½
108	Oct. 4	B—EW		16 15.6 .		16 21.9		0.2	
		B—NS	16 11.8			27.0		0.15	
109	Oct. 10	B—EW				23 10		0.3	
		B—NS				8		0.15	

* = well defined. † = gradual.

REMARKS.

Measurements not conveniently included in the scheme of the table are given below. Some slight shocks are described under the head of microseisms.

The three values of the distance computed by the Laska formulae,

$$(1) \quad \Delta = S - P - I.$$
$$(2) \quad \Delta = 1/3\,(L - P).$$
$$(3) \quad \Delta = 1/2\,(L - S + I).$$

nearly always decrease from (1) to (3). The mean, which usually differs but little from (2), is apparently not far from the truth.

95. A weak shock extending over many minutes. Small motion shown on Wiechert. Slow microseisms during the day.

96. A slight shock of small irregular waves. B-E W strongest portion from 6 h 38.1 m to 42.5 m, with a lull from 40.2 m to 41.6 m. B-N S from 6 h 37.8 m to 41.4 m, with a lull from 38.8 m to 40.9 m. Nothing definite on W.

97. Tremors died out very gradually. W-N S record imperfect but recorded motion is of very small amplitude. On B-N S there is a stronger group of sinusoidal waves in the tail from 10 h 26.4 m to 29.4 m.

98. It is possible that S and L have been misidentified.

100. B-E W small waves beginning about 6 h 9 m coming to a maximum at 17.5 m, dying away again in a few minutes. B-N S same. Also shown on W-N S.

101. B-E W small waves beginning 6 h 34 m, gradually increasing. B-N S tremors begin gradually about 6 h 32 m. W-E W waves of maximum amplitude 0.2 mm from 6 h 53 m to 57 m. W-N S trace? W-V slight tremors (amplitude scarcely 0.1 mm) from 6 h 53.8 m to 57.3 m.

102. B-E W undulations last for half an hour after M, starting up again 70 m after M. B-N S undulations cease about 10 m after M but start up again about 70 m after M.

103. The stronger waves show for 2 or 3 m on W-E W. The slightest irregular trace on W-N S.

106. W-V record poor. Long waves began at 16 h 47.8 m and ended at 53.4 m.

107. The Panama earthquake.

108. A small record. No well marked phases.

109. A weak disturbance having a gradual increase and decrease in intensity.

MICROSEISMS.

The characteristic features of the microseismic disturbances recorded here have been described and discussed in previous reports.

The microseisms recorded as "groups of sinusoidal waves" may in some cases be due to the passage of trains on tracks one-half kilometer north. There is some evidence, however, that these are real seismic tremors which are assisted in recording themselves by the rapid vibrations given the pen by trains. In this connection see *Hobbs' Earthquakes*, p. 264. It appears that train effects are not the same, or even of the same general character, at all times.

MICROSEISMS 1913.

1913.

Jan. 1-7.
Irregular sinusoidal waves on the B instruments. Traces on W. On Jan. 3-4 stronger EW than NS.

Jan. 7-9.
Small irregular motions but nearly continuous.

Jan. 8-13.
Regular sinusoidal waves of small amplitude, increasing to a maximum on 9-10, and then dying away very slowly.

Jan. 13-14.
As above but more active.

Jan. 14-15.
Traces.

Jan. 20-23.
Weak sinusoidal tremors.

Jan. 28-29.
Small groups of sinusoidal tremors on B and W.

Jan. 29-30.
Same but weaker.

Jan. 31-Feb. 1.
Tremors, more or less continuous shown by B—NS.

Feb. 1-10.
B—EW groups of sinusoidal waves. B—NS nearly continuous tremors. Motions of very small amplitude recorded on W.

Feb. 3-4.
B—NS shows groups of sinusoidal tremors with very small waves connecting the groups.

Feb. 5-8.
Stronger. B—NS shows continuous motion.

Feb. 8-9.
Feebler.

Feb. 9-10.
Somewhat stronger.

Feb. 13-14.
Tremors throughout day, best recorded by B—NS as during all this period.

Feb. 14-15.
Groups of tremors showing more plainly on NS records.

Feb. 22-23.
Groups of sinusoidal tremors. Motion nearly continuous on B—NS.

Feb. 23-24.
Continuous motion by B—NS.

Feb. 24-25.
Traces nearly all day B—NS.
The amplitudes of the tremors during January and February have been small, scarcely exceeding one or two tenths of a millimeter.

March 1-2.
B—EW a few slight tremors in latter part of day. B—NS strong irregular tremors during the last few hours. Effects are seen on W records.

March 2-3.
B—NS small tremors all day with groups of stronger irregular waves.

March 5-6.
B—NS lines slightly wavy all day.

March 6-7.
Same. Slight irregularities shown by B—EW.

March 7-8.
Very slight slow motion indicated by B—EW with a few groups of sinusoidal waves of about 0.1 mm amplitude.

March 9-10.
B—NS small undulations in morning, gradually dying away.

March 15-18.
Slight tremors.

March 21-22.
B—NS microseisms beginning between 8 and 9 o'clock, quite strong for 5 or 6 hours, continue all day with diminished intensty; amplitude 0.5 mm, occasionally 0.7 mm. B—EW shows waves of 0.2 or 0.3 mm amplitude during strongest period on NS. Some evidences of action on W.

March 28-29.
B—EW small sinusoidal waves throughout most of day. Trains seem to assist pen to record.

March 29-30.
B—NS slight disturbances throughout the day.

March 31-April 1.
B—NS feeble tremors particularly in first half of day.

April 1-2.
Feeble sinusoidal microseisms on B—NS.

April 4-7.
B—NS lines slightly wavy. Traces on W?

April 30.
B—EW irregular waving of the pen from about 6h 0m to 30m; amplitude 0.1 mm ±. B—NS same, with even smaller amplitude.

May 9-11.
Very small sinusoidal waves.

May 17-18.
B—EW groups of sinusoidal waves throughout the day—trains? B—NS same but weaker.

May 18-19.
Small waves and irregularities throughout the day on B instruments.

May 19-20.
Same, very slight.

June 8-17.
Throughout this period there are numerous well-marked groups of sinusoidal waves of period 5 s ±, extending over a minute or so. These may be due to trains.

July 12.
B—NS a few irregular microseisms from 9h to about 20h.

July 28.
B—NS slow microseisms or a feeble indefinite shock at 0h 15m. Shown on B—EW with strongest motion at 0h 11m.

Sept. 3.
Microseismic shock from 15h 51m to 16h 12m on B—EW; from 15h 44m to 16h 17m on B—NS.

Sept. 4-7.
B—EW irregular microseisms. Less conspicuously present on B—NS.

Sept. 14-15.
Microseisms of very small amplitude on B instruments.

Sept. 20-23.
Slow microseisms of very small amplitude on B—NS, with traces on B—EW.

Sept. 30-Oct. 1.
Some feeble irregular microseisms on B instruments.

Oct. 1-5.
W—EW shows occasional irregular disturbances.

Oct. 6-10.
B—EW a few weak microseisms.

Oct. 10-11.
B—NS shows weak disturbances similar to above.

Oct. 11-15.
Small microseisms on B instruments.

Oct. 14.
B—NS a maximum of slow waves of period ½ m about 3h om. The waves are seen on B—EW but maximum is 8 or 10m later.

Oct. 15-16.
Weak microseisms of short period.

Oct. 16-17.
Trains seem to have an unusually strong effect. This has been noticed on other occasions.

Oct. 16.
B—NS shows slow irregular movements beginning about 15h and lasting for several hours. Less extensively recorded on B—EW.

Oct. 17-18.
B—NS lines irregularly wavy in small amplitude all day. A little of the same seen on B—EW.

Oct. 18-19.
The above dies away.

Oct. 22-23.
Sinusoidal microseisms of period 4 or 5 s and amplitude 0.1 mm are shown on B instruments, being better marked on B—EW.

Oct. 23-24.
B—EW above shown: there are larger waves (period 20 s) of amplitude 0.2 mm beginning about 8h 18m on Oct. 23, lasting for 5 or 6 m. Traces of same on B—NS.

Nov. 1-3.
B—NS and weaker on B—EW small rather irregular disturbances throughout day, which continue with about the same characteristics until Nov. 13.

Nov. 10.
Groups of waves shown as follows:

INST.	TIME	PERIOD	AMPLITUDE
	h m m	s	mm.
B—EW	16 9 to 14		
	16 to 20	20	0.2
	20 to 27		
B—NS	18	20–25	0.15
W—EW	9 to 14		
	15 to 27	23	0.1

Only slightest trace on W—NS.

Nov. 21-22.
B instruments sinusoidal waves of short period and small amplitude, being stronger early in the day.

Nov. 22-23.
Weaker.

Nov. 23-24.
Stronger.

Nov. 24-27.
Same.

Nov. 27-28.
Fainter. Motion of trains exaggerated on B—EW showing waves 12s long.

Dec. 3-6.
Slight microseisms, being very weak on 4-5.

Dec. 5.
B—EW regular sinusoidal waves all day. Well marked group of waves of amplitude 0.3 mm beginning at 18h 29.5 m and stopping abruptly at 31.0 m.; Period of waves, 4s. B—NS irregular sinusoidal waves of 0.2 mm amplitude begin at 18h 26.4m, continuing to 30.2m after which they gradually die out. W—EW regular sinusoidal waves from 18h 29.7m to 31.1m; amplitude 0.3 mm, period 4 + s; beginning of disturbance at 18h 21.7m?

Dec. 6-12.
B instruments and W—EW show sinusoidal disturbances which are stronger on 8-9.

Dec. 12-15.
Small irregular waves on B—EW which are stronger on 12-13.

Dec. 15-27.
Sinusoidal microseisms throughout this period B—EW, B—NS, W—EW. Strongest 20-21.

Dec. 27-28.
B—NS numerous groups of regular sinusoidal waves, amplitude 0.1 to 0.4 mm, period 6s, with fainter waves connecting the groups. B—EW record imperfect but similar waves shown. W—EW similar waves, amplitude 0.2 mm, period 5s.

Dec. 28-29.
B—EW many sinusoidal waves particularly in early part of day, amplitude 0.3 mm, period 5-6s. B—NS same but weaker. Waves of smaller amplitude shown on W instruments.

ERRATA

Page 14, Column 1, Line 8: For 20″.565, Read 20″.656.

Other determinations are available as follows:

Urie	20″.699
Lindsay	20″.707
Dawson	20″.634

Page 34, Last line: For May 1900, Read May 1912.

Page 41, Plate VIII: For Cillimator, Read Collimator.

Page 42, Second line of table: For 5,700 and 0.79Å, Read 4,000 and 1.12Å respectively.

NOTE ON SPECTROGRAPH DESIGN.

On page 37 of this volume, column 2, lines 39 to 42, Mr. W. H. Wright is mentioned by the author as the designer of the "Southern Mills Spectrograph"; and on page 43, column 2, lines 20 to 24, he is named as the inventor of the *type* of instrument adapted to single-prism construction at the Allegheny Observatory. These allusions to the development of the stellar spectrograph do not take into account the important work of Director W. W. Campbell of the Lick Observatory, from whose writings it is my pleasure to make the following quotations, by which any reference of mine in this connection should be superseded.

"A three-prism spectrograph, constructed in our instrument shop from my drawings, embodied the results of many conferences between Mr. Wright and myself." From *Publications of the Lick Observatory,* Vol. IX, page 6; under title, "Organization and History of the D. O. Mills Expedition to the Southern Hemisphere."

"My assistant and colleague, Wright, suggested that such an instrument should be supported *near its two ends,* like a bridge truss or beam, in order to give minimum flexure. Acting upon this suggestion I designed the supports of the spectrograph of the D. O. Mills Expedition to Chile, in 1901, as shown in the illustration....." From *Stellar Motions,* Chapter II, page 47.

R. H. CURTISS.

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